Research Report
KTC-02-07/SPR197-99& SPR218-00-1F

KENTUCKY TRANSPORTATION CENTER

College of Engineering

THE COST OF CONSTRUCTION DELAYS AND TRAFFIC CONTROL FOR LIFE-CYCLE COST ANALYSIS OF PAVEMENTS

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THE COST OF CONSTRUCTION DELAYS AND TRAFFIC CONTROL FOR LIFE-CYCLE COST ANALYSIS OF PAVEMENTS

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Kentucky Transportation Cabinet
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Executive summary

The objective of this report is to provide the Kentucky Transportation Cabinet a reliable approach to quantifying/calculating “Road User Cost”--often referred to as total user delay costs. To meet this objective, this report is divided into three main sections. The first section summarizes the reviews of three relatively new computer programs that can be used to help quantify delayed traffic incurred by the presence of a work zone. From this review, one program was selected based on it’s user friendliness and ability to define both quantity of delayed traffic and queue length. The second section compares actual field data to the output of the selected program to help determine the program’s reliability/predictability in determining both quantity of delayed traffic and queue lengths. The last section summarizes typical hourly user cost rates by vehicle type (i.e.: vehicle operating costs, delay costs, and accident/crash costs) that have been used by other agencies. By combining the output from the selected program, and these typical user cost rates, one may be able to determine the total user delay costs associated with a highway construction project.

I. Introduction and background

Recently the Federal Highway Administration (FHWA) has encouraged State Highway Agencies to perform life-cycle-cost analysis on new highway construction/rehabilitation projects. One of the major items of such an analysis is defining road user costs. Road user costs, commonly referred to as total user delay costs, are defined as an aggregation of vehicle-operating-costs, user delay costs (i.e.: value of time), and accident/crash costs.[4,13] However, the ability to quantify delayed traffic, which is used to calculate total user delay cost, has not been well documented for construction zones until recently.

To help pavement designers better define road user costs, associated with work zones. This report will summarize the reviews of three relatively new computer programs that can be used to help quantify delayed traffic incurred by the presence of a work zone. From this review, one program will be selected based on it's user friendliness and ability to define both quantity of delayed traffic and queue length. Next, actual field data will be compared to the output of the selected program to help determine the programs reliability/predictability.

Additionally, this report will summarize typical hourly user costs rates by vehicle type that have been used by other agencies. By combining the output from the selected program, and these typical user cost rates, one may be able to determine the total user delay costs associated with a highway construction project. Ultimately, it is anticipated that one may use the total user delay cost to assist in performing a life-cycle-cost analysis on a new highway construction/rehabilitation project.

II. Review of construction zone user costs programs

A. QuickZone delay estimation program (Version 0.99)

In 1998 the Federal Highway Administration (FHWA) produced a report titled "Meeting the Customer's Needs for Mobility and Safety During Construction and Maintenance Operations" which recommended the development of an analytical tool to estimate and quantify work zone delays. To this end, the FHWA proceeded with the development of QuickZone, a work zone delay estimation program developed in Microsoft Excel.

The QuickZone program ideally lends itself to urban work zone planning. It has the capability of quantifying corridor delay resulting from capacity decreases in work zones; identifying delay impacts of alternative project phasing plans; and supports tradeoff analyses between construction costs and delay costs.[1] However, this program is more sophisticated than the other two programs that will be discussed below and will require the user to enter a great deal more of information concerning a particular project.

To use the QuickZone program the user must first create a network of traffic facilities. Each network is built from a system of nodes that are linked to each other by user defined links. Nodes are the simplest element of a QuickZone network.[1] Nodes generally represent a roadway intersection and determine the beginning and end of a road or link. Links are quoted in the QuickZone user's manual as being the heart of the network. Each link in a network is defined as either a mainline, detour, or a work-zone. In addition, links include most of the attributes that are used within the QuickZone algorithm such as: number of lanes, free-flow speed, capacity, jam density, length, direction, type and position. The QuickZone user's manual advises that approximately three hours may be needed to input information into the program to create a network. This does not account for the time needed to research/collect necessary traffic data.

Once a network has been finalized and input into the program the next step is to run a simulation on the network to calculate backups on the mainline, alternate routes, and detours for different phases/scenarios of the construction process. This backup/queue estimating process is mathematically calculated in the program by comparing the expected travel demand against proposed capacity by facility on an hour-by-hour basis for the life of the project. Ultimately these calculated backups are used to calculate total user delay costs that in turn can be used in an life-cycle-cost analysis.

Although the QuickZone program can be used to calculate many different attributes about work zone delays in a particular network, it should be mentioned that there may be several drawbacks to using this program to determine road user costs. First, QuickZone does not calculate a reduced work zone capacity value. This is a much needed value that will be used to calculate the lengths or volumes of queued traffic. QuickZone recommends that the user refer to the 1994 Highway Capacity Manual (HCM) for defining work zone capacity reductions if the user is unaware of an appropriate value. Second, data entered to estimate user delay costs (i.e.: value of time) are based on a single vehicle per hour cost and a user defined inflation rate. QuickZone offers no distinction between user delay costs for that of passenger cars and trucks, and no directive as to defining a applicable inflation rate.

Based on both the depth of traffic information that must be input to create a network, and that the user must have prior knowledge of the work zone capacity, it would appear that the QuickZone program does not adequately meet the objectives of this study. It also appears that this program may insufficiently address road user costs since the user is advised to only input a delay cost per vehicle hour and a inflation rate. In addition, the QuickZone program may not be as user friendly or as simplistic as the other two reviewed programs. However, if the overall impact of traffic delay was to be defined in an urban area, the QuickZone program is the only program reviewed in this study that addresses traffic impacts on multiple facilities to any great detail. It should also be mentioned that the QuickZone (version 0.99) reviewed in this study was a fourth generation beta testing version. A modified public version number (1.0) is to be released in early 2002.

B. QUEWZ-98

The original QUEWZ, Queue and User Cost Evaluation of Work Zones, mainframe program was developed in 1982 at the Texas Transportation Institute (TTI).[2] Over the course of sixteen years the QUEWZ program has been upgraded numerous times. The most recent upgrade version is QUEWZ-98.

QUEWZ-98 is a DOS-based microcomputer analysis tool used for planning and scheduling short-term work zone lane closures on freeway facilities. The program analyzes traffic conditions on a freeway segment with and without a lane closure in place and provides estimates of both the additional road user costs and queuing. The road user costs calculated in QUEWZ-98 includes travel time, vehicle operating costs, and excess emissions.[2]

The QUEWZ-98 program, much like the other reviewed programs, does require vital user input in order to properly analyze construction zone delays. The user will be required to enter items such as: AADT or hourly directional traffic counts, percentage of trucks in the traffic stream, normal operation capacity values, length of work zone, a cost update value to adjust default road user costs for the effect of inflation, day of week, hours that the construction zone is in place, schedule of work activity, work zone configuration, definition of excessive queuing, and work zone capacity.

After a through review of the QUEWZ-98 program, there were four unique features observed that are worth noting. First, the QUEWZ-98 program has the ability to calculate work zone capacity based on user input. The QUEWZ-98 program uses a new work zone capacity equation that greatly improves the accuracy of predicting work zone capacity from that seen in earlier versions of the QUEWZ program. This particular equation, which will be discussed in further detail in the "Up-dates to existing program" section of this report, is currently recognized in the 2000 Highway Capacity Manual (HCM). Second, the QUEWZ-98 program has an optional feature that allows the user to adjust traffic demand for vehicles that may use an alternate route. QUEWZ-98 defines this as the diversion algorithm. Third, QUEWZ-98 allows users to evaluate a work zone either by defining road user costs or by optimizing the lane closure schedule. If a user selects the lane closure schedule feature and enters all required traffic data, the QUEWZ-98 program will graphically display which hours a lane closure should be scheduled in order to produce the least amount of delay. Lastly, the QUEWZ-98 program has the ability to estimate idling emissions rates in grams of HC, CO, and NOx per hour for each vehicle type.

As mentioned above, there are several useful attributes contained in the QUEWZ-98 program. However, this program contains a few items that may not be desirable for analyzing construction delays and highway road user costs in Kentucky. First, QUEWZ-98 is a DOS based program. Printing output may be a problem for computers that are connected through a TCIP network, and file names are limited to a eight character format. Second, the diversion algorithm is based upon observations of work zone lane closures on urban freeways with continuous parallel frontage roads in Texas.[2] Third, the process of estimating queue lengths is based on procedures identified in the 1994 HCM This procedure uses a vehicle equivalent length factor to determine the total length of the backup. By default, QUEWZ-98 assigns an equivalent vehicle length of 40 feet to all vehicles that are delayed. The equation involves subtracting work zone capacity from demand then multiplying this result (queued vehicles) by 40 feet. This product is then divided by the number of available lanes to produce a queue length in feet.[3] Fourth, the queue estimating equation will not carry delayed traffic into the 12:00-1:00 a.m. hour regardless of the size of queue experienced in the previous 11:00-12:00 p.m. hour. Lastly, both volume and directional distributions estimations based on time-of-day and day-of-week were formulated from automatic traffic counters located throughout the state of Texas.[2] These estimated values cannot be changed, and may not apply to local conditions.

In summary the QUEWZ-98 program has many useful attributes that address the designer's needs of identifying delayed traffic and road user costs in construction zone areas. However, with the above mentioned deficiencies, it is suggested that the QUEWZ-98 program may have limited use for determining total user delay costs, and/or time schedules for lane closures that will produce excessive delays.

C. Demonstration project 115 (DP-115)

During FHWA's Demonstration Project 115 (DP-115), a program titled "Life-Cycle-Cost Analysis in Pavement Design" was developed. Contrary to the program's original title, this program does not actually calculate life-cycle-cost for pavement design. Rather it calculates road user costs, which is a component of an life-cycle-cost analysis. Therefore, for simplicity, this program will be referred to as the DP-115 program throughout the remainder of this report.

Unfortunately, FHWA has not released a computer copy of the DP-115 program. However, the technical bulletin (FHWA-SA-98-079) outlines a step-by-step procedure of how this computer program should be set up in Microsoft Excel. The Kentucky Transportation Center's Pavement Section was able to program the DP-115 program in Excel in about three to four weeks. Once the program was set up, a thorough review was made on the calculating procedures used for determining both queue length and road user costs. In addition, field data was collected from both short-term and long-term work zones in Kentucky and compared to DP-115 output to determine the program's reliability/predictability. The comparison of field data to that of the DP-115 program output will be addressed later in this report.

Although it is believed that the DP-115 program addresses many of the desired objectives of this study. This program does have its limitations. There are some areas of the program that need to be up-dated/enhanced from its original version. The following paragraphs discuss the strong and weak points. Further discussion of the up-dates/enhancements to the DP-115 program will be given in the next section of this report.

First, the DP-115 program is designed in Microsoft Excel for Windows format. Which allows for ease of using and transferring the program from one computer to next. Second, the cost updating factors used for determining road user costs, in present day dollars, can easily be adjusted by the nationally known Consumer Price Index (CPI) data. The process of inflating user costs values in the DP-115 program has been very well documented in the technical bulletin, and the CPI data can be obtained from the U.S. Bureau of Labor Statistics website (http://stats.bls.gov/cpihome.htm). Third, the DP-115 program can evaluate a work zone with traffic volume entered in either an AADT or hourly directional volume format. In addition, the user is able to change the default multiplying factors for both directional splits and hourly distributions of traffic. Fourth, the process of determining queue length is based on roadway density rather than a vehicle equivalent length. Research has shown that the vehicle equivalent length approach in most cases underestimates actual queue length.[4] Fifth, the DP-115 program is capable of carrying over queue lengths from the 11:00-12:00 p.m. hour to the 12:00-1:00 a.m. hour. Lastly, the DP-115 calculates road user cost by volume of delay and not length of delay. As seen later in this report, identifying the correct length of queued traffic may not always be the same for different construction zones mostly because drivers will merge into the open lane/lanes depending on traffic congestion and traffic control.

As mentioned above there are many useful attributes in the DP-115 program; however, there are several items that may need to be enhanced/up-dated to calculate road user costs more accurately. First, the process of calculating work zone capacity has been based on research provided in the 1994 HCM. As shown in the QUEWZ-98 program, a more accurate and up-to-date process is now available (see Up-dates to existing program section). Second, the queue estimating equation has the ability to become involved in a circular reference if all 24 hours of the day are experiencing delayed traffic. To avoid this unwanted scenario, a zero value has been placed in the demand-minus-capacity-equation for the 3:00-4:00 a.m. hour. Third, the program user will have to manually optimize a work zone schedule to produce the least amount of delayed traffic, unlike that found in the optimization feature of the QUEWZ-98 program. Lastly, in the DP-115 report, the combination truck value in table 3.24 should be $721.77 instead of $178.98.

Provided that one addresses the minor problems listed above, it is believed that the DP-115 program will assist designers in more accurately defining road user costs associated with highway work zones. It also appears that the DP-115 program will assist in scheduling lane closures that will produce the least amount of delays.

III. Proposed program "Demonstration Project 115" (DP-115)

A. Up-dates to existing program

After the review/evaluation of the of the QuickZone program, QUEWZ-98 program, and the Life-Cycle Cost Analysis in Pavement Design developed in the FHWA Demonstration Project 115, the researchers are recommending the DP-115 be used in determining road user costs. However, with this recommendation five modifications have been proposed to up-grade the original program. The new up-graded version of the DP-115 program, based on the modifications listed below, will be referred to as the Kentucky User Cost Program version 1.00 (KyUCP) later in this report.

The first modification is the use of the new short-term work zone capacity equation developed by the Texas Transportation Institute (TTI) and endorsed by the National Research Council in the 2000 Highway Capacity Manual (see next page). Although this equation was developed in Texas with a lower percentage of trucks, Figure 1 details actual short-term work zone capacities found on three interstates in Kentucky that had truck percentages ranging from 12 to 44 percent. As seen in figure 1, the red trend-line derived from the short-term work zone equation using higher percentages of trucks, matches the actual field data trend-line (in green). It should be mentioned that thirty-six hours of collected traffic data was used to generate the field data trend-line shown in Figure 1. It should also be noted that the HCM defines short-term work zones as highway construction sites that use channeling devices (traffic cones, drums) to demarcate the work area, and construction schedules that may last for just a few days/hours.[6]

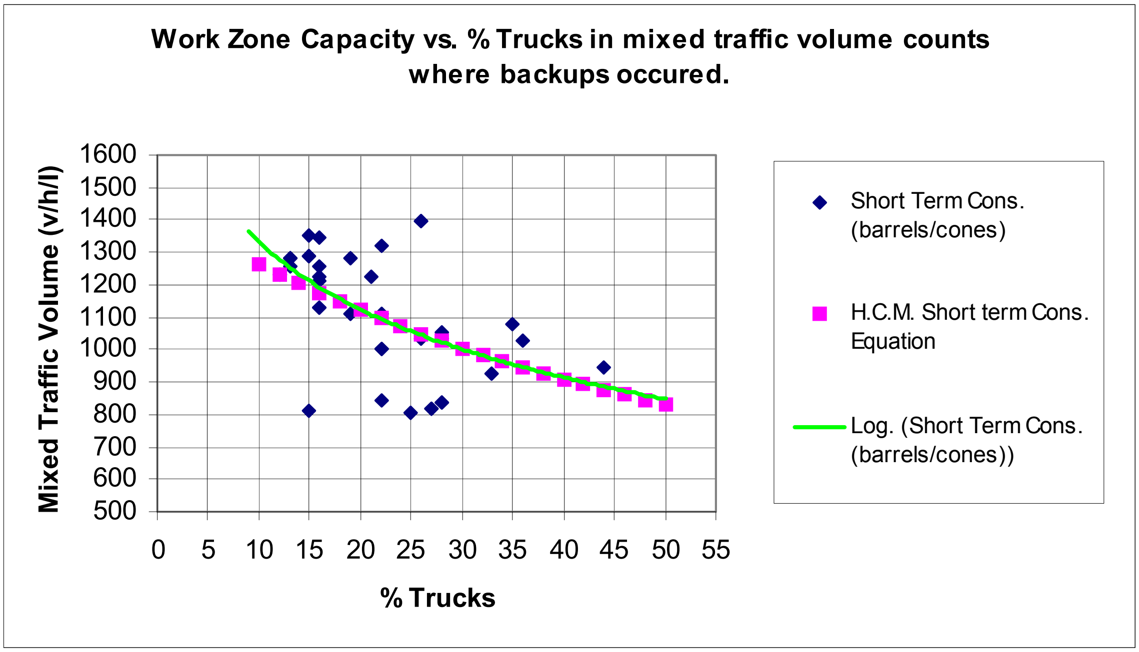

Figure 1: Field data compared to the H.C.M. short term work zone capacity equation

Short-term work zone capacity equation (source 2000 H.C.M):

$$c = (1600 \text{ pcphpl} + I - R) \times H \times N$$

where

c	=	estimated work zone capacity (vph)
I	=	adjustment for the type and intensity of work activity (pcphpl)
R	=	adjustment for the presence of ramps
H	=	heavy vehicle adjustment factor (vehicles/passenger car)
N	=	number of lanes open through work zone

Note that the recommended values for the various adjustments are as follows:

I	=	range {-160 to +160 pcphpl} depending on the type, intensity and location of work activity
R	=	minimum of {average entrance ramp volume in pcphpl during the lane closure period for ramps located within the channelizing taper or within 500 ft. downstream of the beginning of the full lane closure, or one half of the capacity of one lane open through the work zone (i.e.: 1600/2N)}
H	=	located in current Basic Freeway Segments section of (HCM)

In regards to the intensity adjustment factor listed in the equation above, further investigation was performed to better define an appropriate intensity value. Traffic data was collected during work activities of different types on Kentucky highways. This data was then compared to values obtained by using the short-term work zone capacity equation. From this comparison, intensity values for different types of construction activities were defined (Table 1). Although these values are not intended to be a standard, they were observations that were made in the field. Additionally, the HCM states that professional judgement should be used when defining this intensity value.[6]

Further evidence of the effect of work intensity has been seen in Illinois. Here a study of traffic characteristics at four, four-lane highway facilities with one lane closure was conducted to determine the effect of the intensity and location of work activity on mean speeds through a work zone. Study results suggest that mean speeds decrease as the intensity of work activity increases. Work intensity was quantified using an index based upon the number of workers, size or equipment, presence of traffic control, and noise and dusts levels at the site. Mean speeds also decreased as the work activity moved closer to the travels lanes. A 2 mph drop in mean speeds was observed for every 3 foot shift of work activity closer to the travel lanes.[5]

Table 1: Construction Intensity Values

INTENSITY	VALUE	WORK ACTIVITY
Low	+160	Median barrier wall, guardrail installation, shoulder construction/ repair work
Light	+80	Pavement repair, spot patching,
Medium	0	Asphalt removal-milling, resurfacing, concrete slab replacement
Moderate	-80	Pavement markers, Striping
Heavy	-160	Bridge Repair

In addition to the adjustment factors listed in the short-term work zone capacity equation, it is believed that a supplemental adjustment factor for lane width reduction should be added to the short-term work zone capacity equation.[6] Applicable values that may be used are as follows: capacity in passenger-cars-per-hour-per-lane (pcphpl) will be reduced by 9 percent if open driving lanes are reduced from 11 feet to 10 feet and by 14 percent if reduced to 9 foot lanes.[6] Again, professional judge should be used when defining lane width reduction.

The second modification is to define road user costs and queue lengths on an hourly basis. Originally, the DP 115 program only identified the road user costs and total queue length on a daily basis. The program, "KyUCP" developed by the researchers displays both attributes on an hourly basis. This feature will result in better work zone time scheduling.

The third modification being suggested is to allow the user to input traffic data that can be used to calculate normal capacity. This feature has been automated in the KyUCP developed by the researchers. With minimum traffic input, the program will execute the steps used in the Basic Freeway Section of the 2000 HCM to calculate hourly volume in vehicles-per-hour (vph). However, the user is not limited to using this feature. They may still use the conventional method of hand calculating normal capacity and input the value manually.

The fourth modification to the program is the ability to link to the Bureau of Labor Statistics homepage inside of the KyUCP. This allows the user to easily retrieve current consumer-price-index values (CPI data) necessary for up-dating vehicle cost factors.

The last modification eliminates the possibility of the queue estimating equation becoming involved in a circular reference, if all 24 hours of the day are experiencing delayed traffic. As mentioned earlier a zero value needs to be placed in the demand minus capacity equation, preferably when traffic volume is at it's lowest level i.e.: the 3:00-4:00 a.m period.

IV. Long-term work zone capacity

Although long-term rehabilitation/new construction projects take place on existing highway corridors, transportation planners in Kentucky have made tremendous efforts to avoid constant delays in these work zones. Some examples of reducing the impact of delayed traffic in long-term work zones include detours, median cross-over lanes, and increasing public awareness by way of public announcements. However, in some long-term work zones, it is almost impossible to avoid traffic delays at some point throughout a given day when peak traffic conditions occur. It should be noted that the Highway Capacity Manual defines a long term work zone as a site with portable concrete barriers that will be in place for several weeks if not longer.

In this investigation, several long-term work zones were studied to help identify when, and under what type of traffic demands, a long-term construction zone would experience delays. Five different long-term work zone sites were investigated. Traffic counts and physical queue lengths were measured and recorded at each site. Additional long-term delay information has been provided by the Indiana Department of Transportation in a research report titled "Traffic Capacity, Speed, and Queue-Discharge Rate of Indiana's Four-Lane Freeway Work Zones."[7] All long-term construction sites studied in this investigation dealt with lane reductions only. No sites contained detours and/or median crossovers.

Much like the analysis performed on the short-term work zones, a relationship between percent trucks, volume (vehicles/hour/lane), and work zone capacity were established. Contrary to popular belief, long-term work zones appear to process more v.p.h. than short-term work zones. After reviewing collected field data from the long-term work zone sites it appears that calculating the work zone capacity of a long-term work zone cannot be accurately achieved by using the, above mentioned, short-term work zone equation. Therefore, a new equation needed to be developed that allowed for higher work zone capacity values. An exponential equation was derived by a regression analysis from delayed traffic data that was observed in both Kentucky and Indiana (Figure 2). Note, this particular equation on average shows a five to ten percent reduction in capacity as that seen in a Level of Service F highway operating facility with a free-flow-speed of 65 mph, and based on the H.C.M. rolling terrain factor of 2.5 for heavy vehicles.

In addition to delayed traffic values, additional traffic data was collected at various long-term work zones to identify when traffic volumes based on percent of trucks did not produce traffic delays. By adding this information to the graph in Figure #2, it appears to support the use of the exponential curve, thus establishing a threshold for which traffic may not backup. This equation was based on data obtained from multi-lane highway type facilities.

Once the long-term work zone capacity value has been found by using the equation below, the user then can use the DP-115 and/or KyUCP to calculate road user costs and queue lengths for long-term work zones. A comparative analysis between observed queue lengths and projected queue lengths generated by the DP-115 program can be seen in the following section "Comparison of estimated queue lengths generated from DP-115 program and actual work zones".

<u>Long-term work zone capacity equation:</u>

$$c = 1963.7e^{-0.0122x}$$

where

c	=	estimated work zone capacity (vph)
x	=	total percent trucks in traffic stream (whole number)

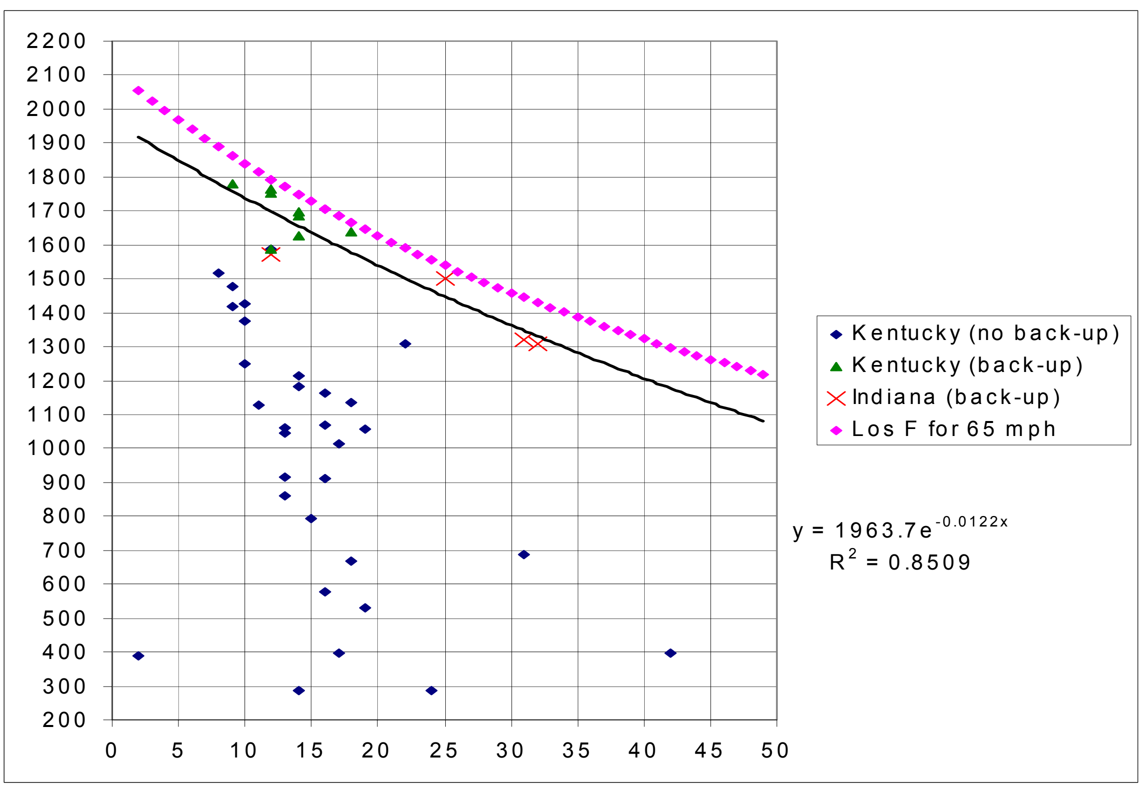

Figure 2: Long term work zone capacity equation/graph

V. Comparison of estimated queue lengths generated from DP-115 program and actual work zones

A. Short-term work zone comparison

Seven different short-term work zones were monitored to compare actual field measured queue lengths to that generated by the DP-115 program. In most cases, the actual field measured queue length fell between the predicted queue lengths derived from the DP-115 program and that of the queue length derived from procedures outlined in the 1994 HCM (see Figures 3 through 9). However, it should be noted that queue lengths may vary based on driver personalities. Consequently, it was outside of the scope of this project to quantify when drivers inadvertently queued themselves into one lane and not into the unoccupied space remaining in the additional lanes leading up to the construction zone. However, research performed by Department of Civil Engineering at the University of Nebraska–Lincoln has made attempts to address this issue by studying the operational effects of the "Late Merge" in traffic work zones. Their findings show that vehicles use the closed lane up to the merge point more as congestion increases.[7] The corresponding data for the Figures 3 through 9 are listed in tabular form in Appendix A. Also note, that the field measured delay curves are for durations of less than 24 hours. This is because the actual traffic count was only performed during these hours, and not a full 24- hour period.

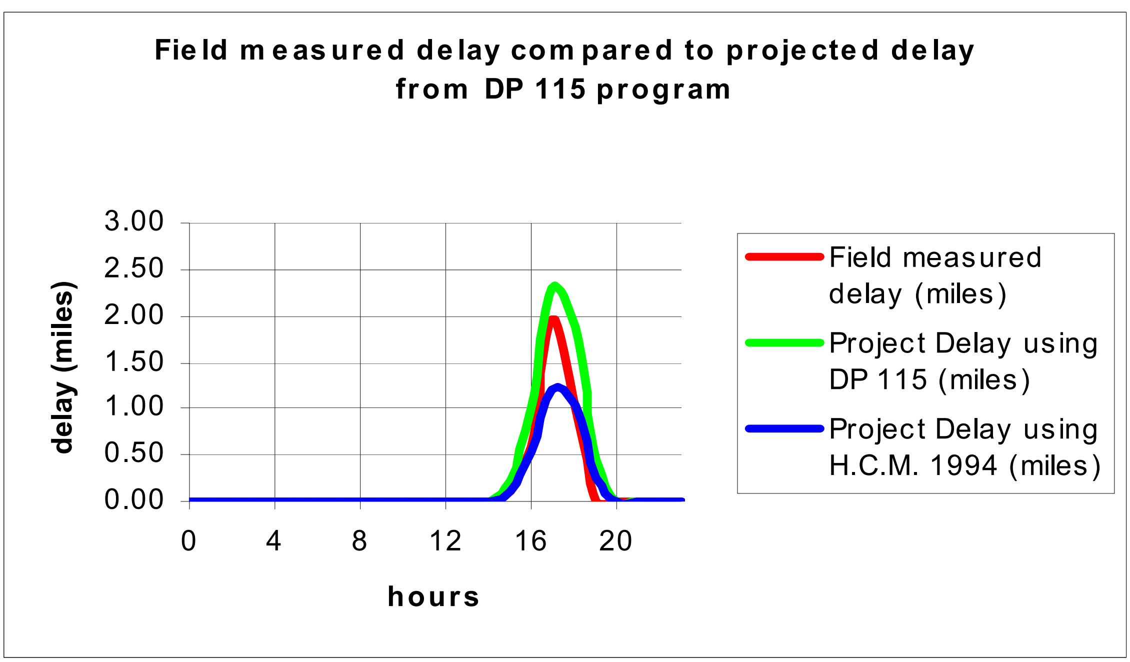

Figure 3: Short-term delay curve, I-64 west, Franklin County, 5/18/99

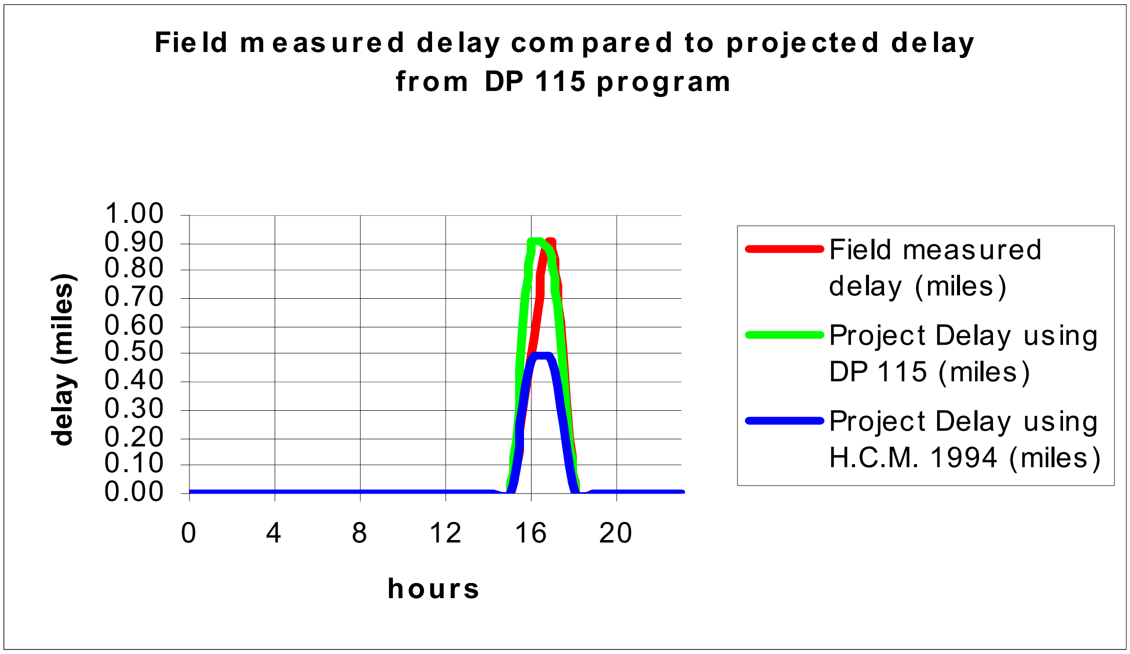

Figure 4: Short-term delay curve, I-64 west, Franklin County, 5/26/99

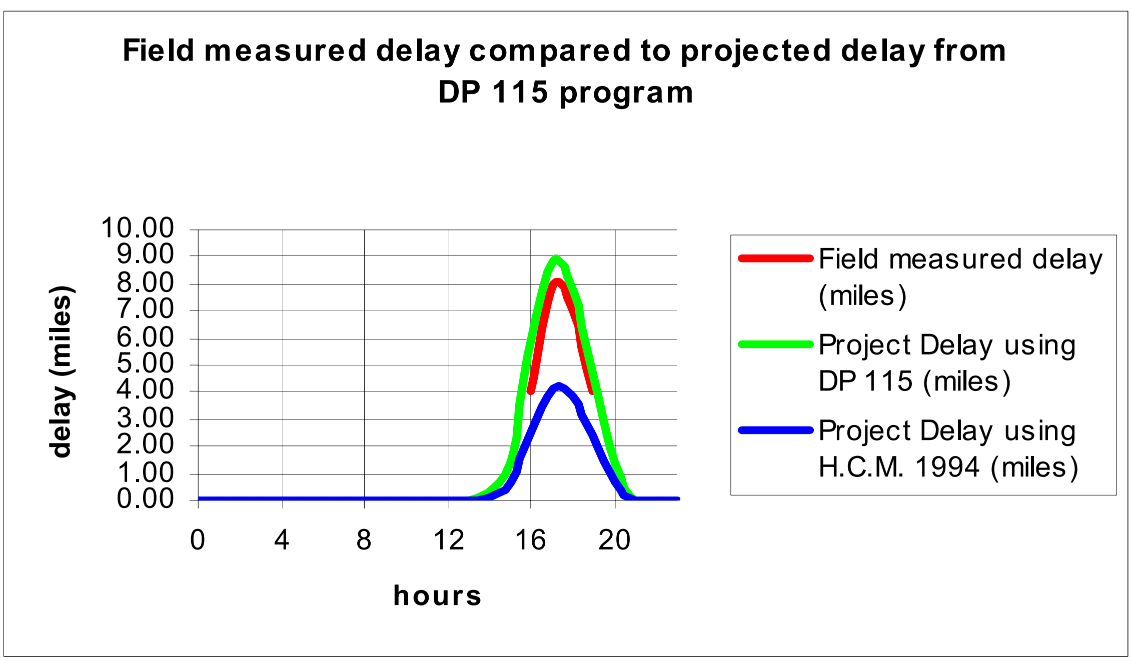

Figure 5: Short-term delay curve, I-75 north, Kenton County, 9/5/01

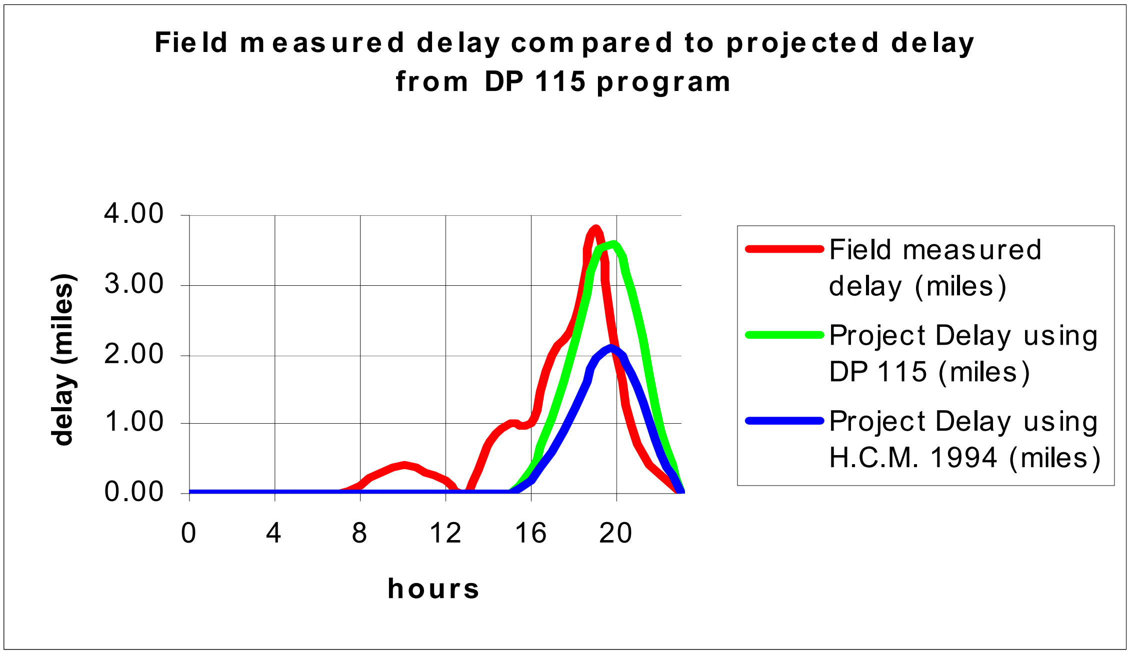

Figure 6: Short-term delay curve, I-64 east, Franklin County, 6/4/99

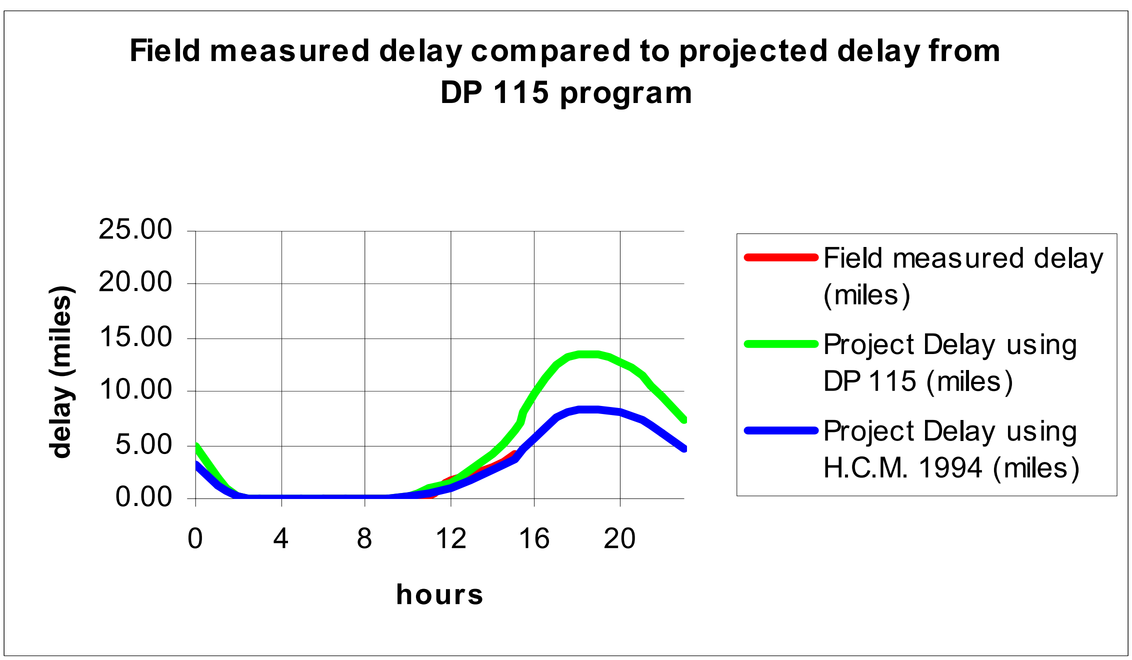

Figure 7: Short-term delay curve, I-65 north, Hardin County, 8/14/01

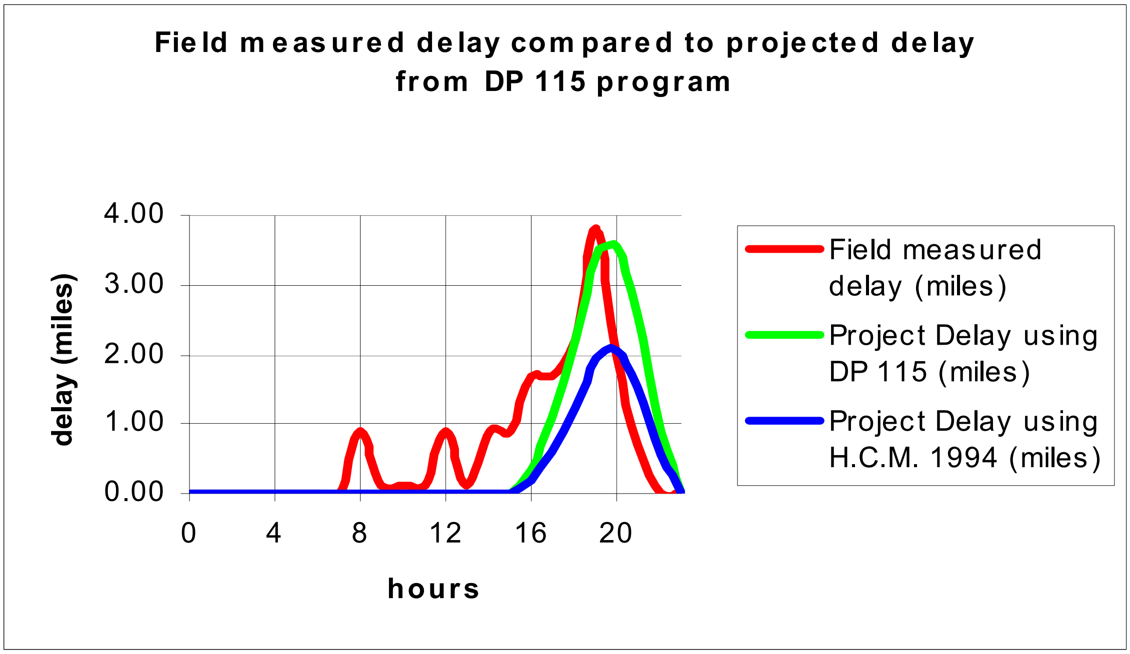

Figure 8: Short-term delay curve, I-64 west, Franklin County, 6/4/99

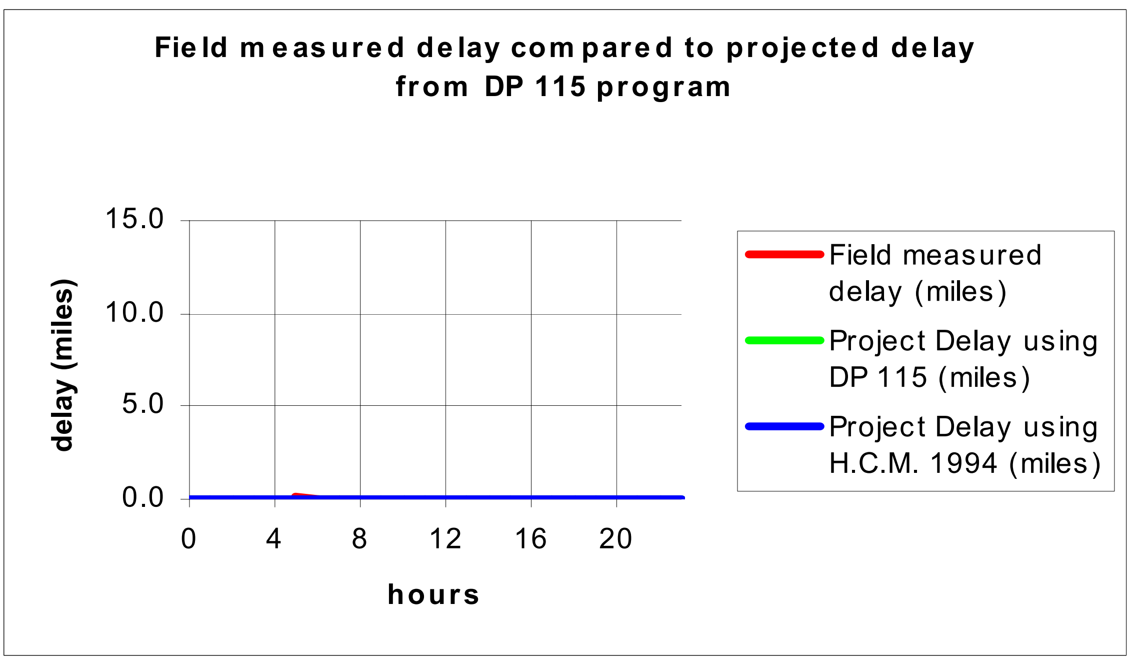

Figure 9: Short-term delay curve, I-75 north, Scott County, 8/21/01

B. Long-term work zone comparison

Five different long-term work zones were monitored to compare actual field measured queue lengths to that generated by the DP-115 program (see Figures 10 through 14). Although, data was used from Indiana's long-term construction zone study to formulate the long term capacity equation, no data was available indicating the associated queue lengths with the congested traffic. In addition, only three out of the five sites studied in Kentucky had actual queued traffic.

The graphs below display the actual field measured queue length compared to the queue lengths generated from both the DP-115 program, and from the queue estimating procedures outlined in the 1994 HCM.

Please note that the field measured delay curves may be chopped off at one end if not both in the graphs below. This is because the actual traffic count was only performed during these hours, and not for a full 24-hour period. The corresponding data for Figures 10 through 14 are listed in Appendix B.

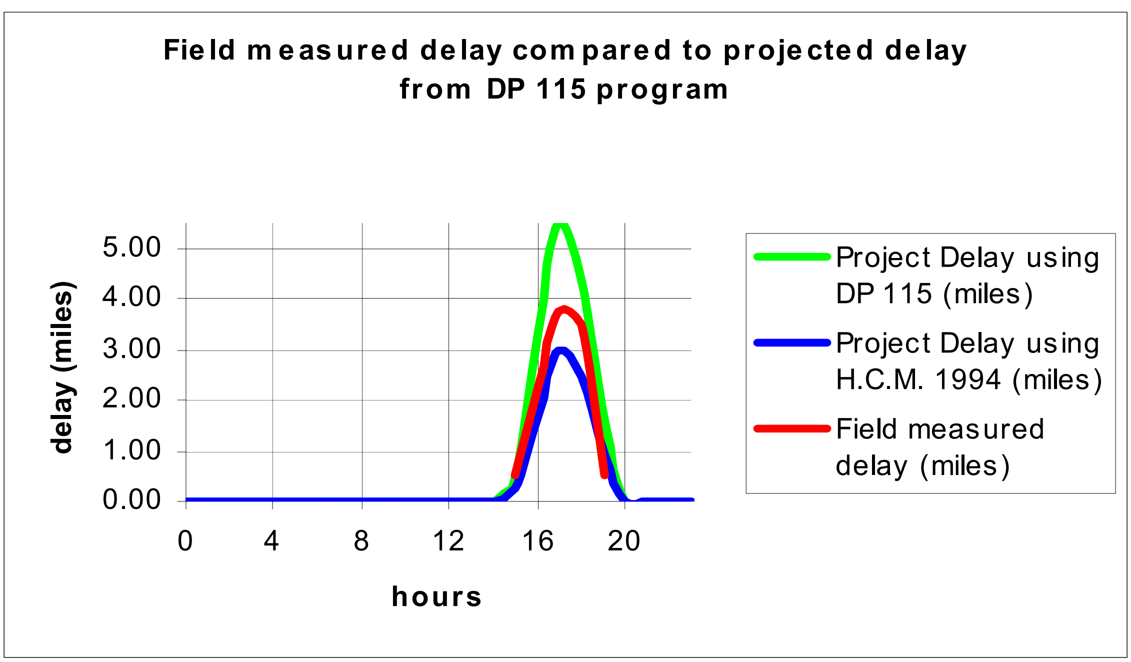

Figure 10: Long-term delay curve, I-75 south, Kenton County, 9/5/01

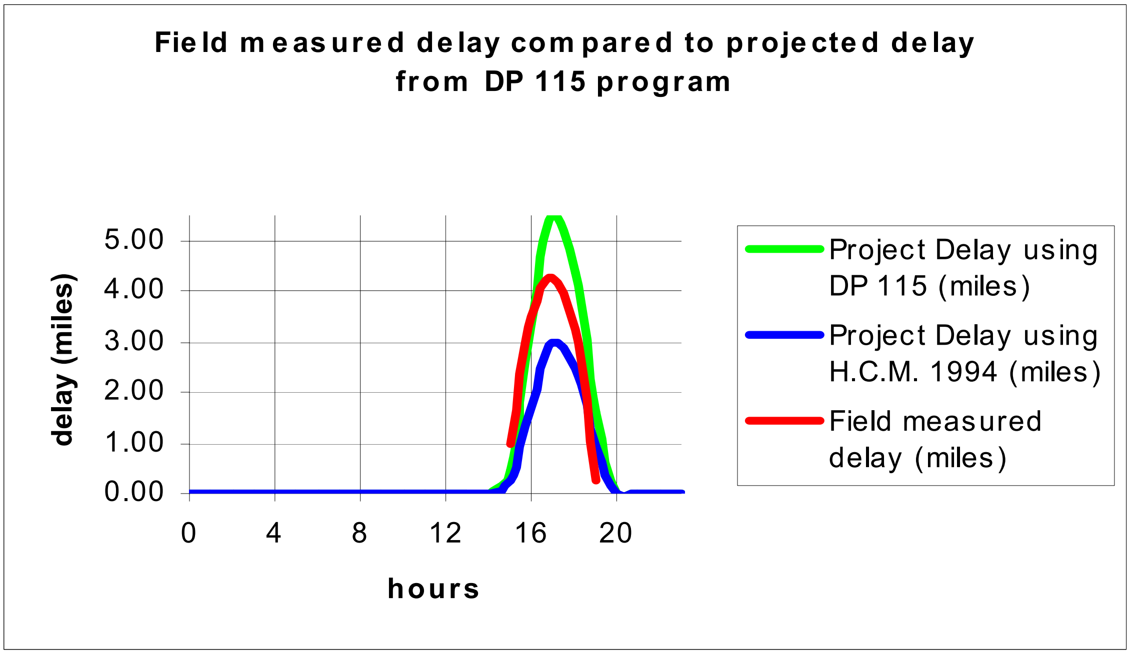

Figure 11: Long-term delay curve, I-75 south, Kenton County, 8/30/01

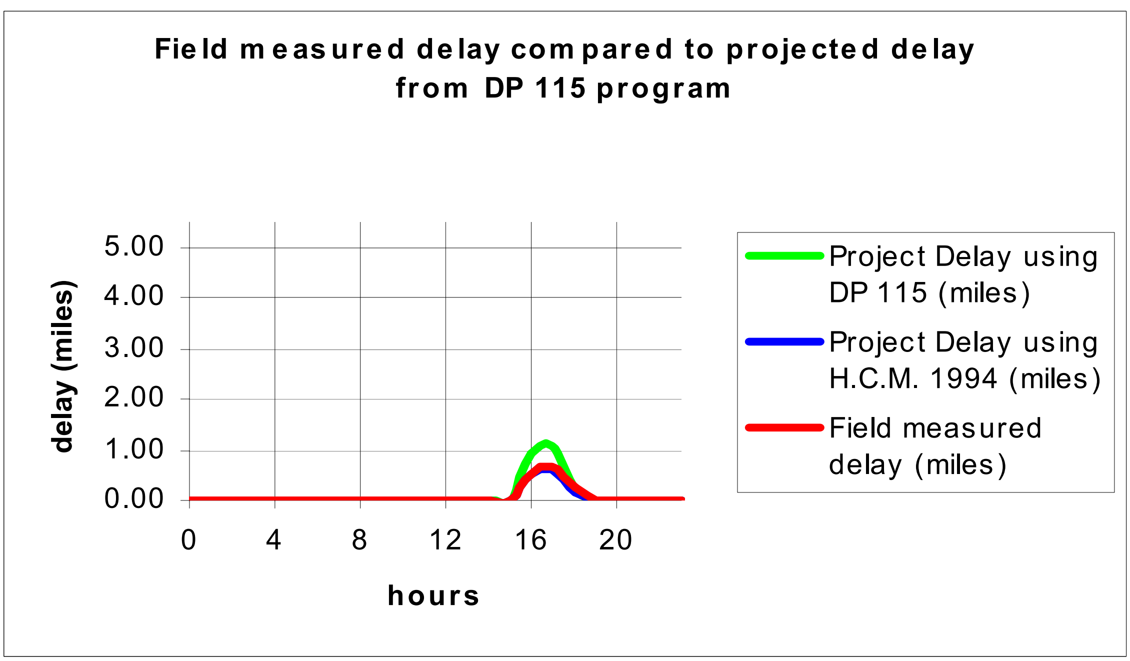

Figure 12: Long-term delay curve, I-264 west, Jefferson County, 6/11/99

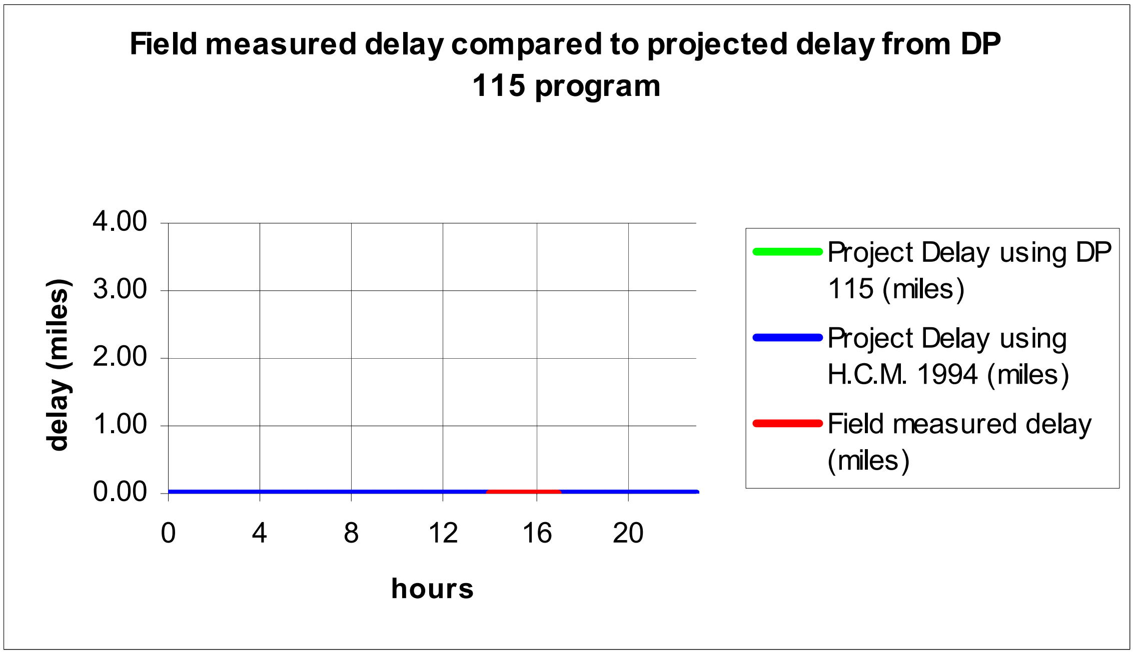

Figure 13: Long-term delay curve, I-75 south, Madison County, 11/21/01

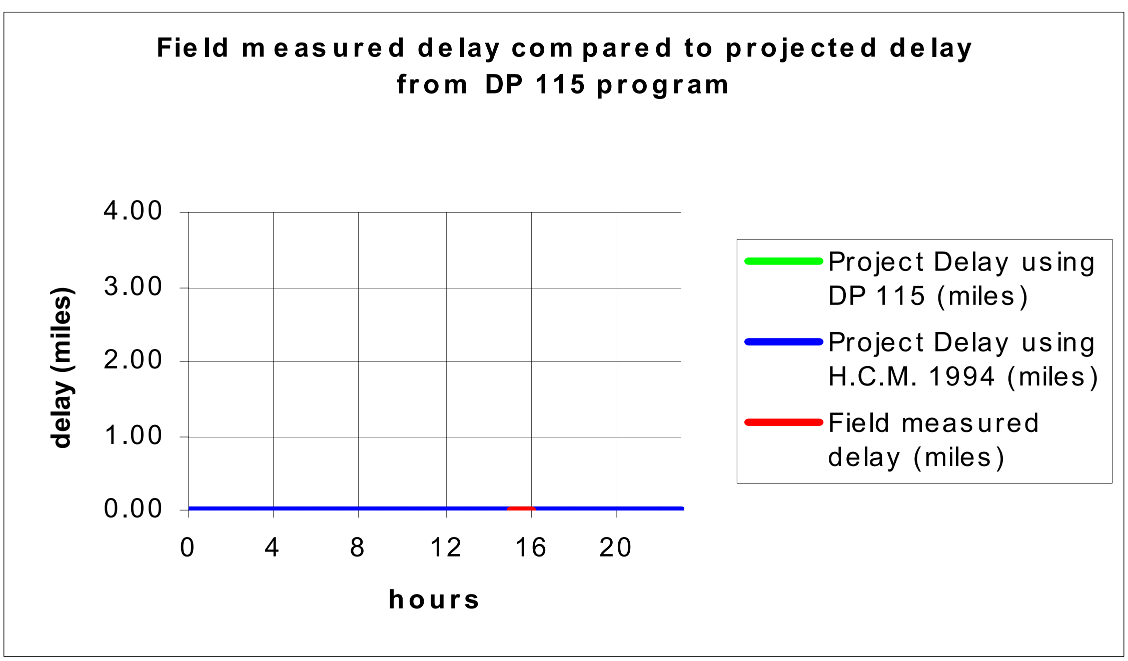

Figure 14: Long-term delay curve, I-64 west, Woodford County, 10/24/01

VI. Road user costs

A. Definition of road user costs and it's components.

"Road User Costs" (RUC), has been defined by researchers at the Texas Transportation Institute as the estimated incremental daily costs to the traveling public resulting from the construction work being performed.[8] Likewise, researchers that authored "Life-Cycle Costs Analysis in Pavement Design" state that RUC are costs incurred by the highway user over the life of the project.[4]

Provided that one agrees with the general definition of "Road User Costs" as mentioned above. The next step is to establish what variables constitute RUC, or what is sometimes referred to as "total user delay costs". Authors of both "Estimating User Costs as a Basis for Incentive/Disincentive Amounts in Highway Construction Contracts", and "Life-Cycle Cost Analysis in Pavement Design" agree that RUC are an aggregation of three separate cost components for three different vehicle types. The three different cost components are; vehicle operating costs (VOC), user delay costs, and crash/accident costs. The three different vehicle types are; passenger cars, single-unit trucks, and combination trucks.

To help better define what monetary values to use for RUC's cost components, an extensive literature search was performed to identify how other agencies define RUC cost components. Based on the findings from this literature search, a summarized RUC list has been generated that will hopefully define applicable cost component ranges for each vehicle type (see cost rates below). However, before the RUC cost components are discussed, it is worth noting the process of up-dating cost components to present day dollars.

Typically user delay cost/VOC data are adjusted to present day dollars by multiplying older costs rates by one or more escalation factors. Normally the escalation factors have been derived by using both the "*Transportation*" and the "*All Items*" components of the Consumer Price Index (CPI). The *transportation component* is used to adjust (VOC) cost rates, and the *all items* component is used to adjust delay costs (i.e.., the value of time).[4] An example of converting a hypothetical five dollars from 1970 dollars to August of 1996 dollars by both the *all items* and *transportation* component can be seen below. CPI values can be viewed at the Department of Labor Statistics Data website.

<u>All Items:</u>

$$\text{Escalation Factor (Value of Time)} = \frac{157.3 \text{ (Aug. 1996)}}{38.8 \text{ (1970)}} = 4.054$$

$5 (1970) x 4.054 = $20.27 (Aug. 1996)

<u>Transportation:</u>

$$\text{Escalation Factor (VOC)} = \frac{142.8 \text{ (Aug. 1996)}}{37.5 \text{ (1970)}} = 3.808$$

$5 (1970) x 3.808 = $19.04 (Aug. 1996)

B. Road user cost components and their rates

It is intended, in this section of the report, that a range of road user cost rates being used in the DP-115 program and by other agencies be summarized. It is beyond the scope of this report to duplicate the means/methods of previous research performed to define applicable road user cost rates for delayed traffic. It should also be noted that the indirect road user costs that may be associated with rolling inventory, or commonly referred to as just-in-time delivery will not be addressed. While such factors are applicable in certain situations, it is felt that this topic is beyond the scope of this study as well.

1. Cost components and their rates used in the DP-115 program

a. VOC rates

The VOC cost rates used in DP-115 (see Table 2 below) were first developed by Winfrey[9], and later revised/updated in NCHRP Report 133, "Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects."[10] Table 2 can be used to determine the additional VOC rates for stopping/speed changes and idling, as well as associated delay times for stopping/speed changes for vehicles that are delayed on the highway facility. If detours are used to allow traffic to by-pass the construction zone the DP-115 technical report suggests using either the marginal costs rates used by the Federal Government or the flat mileage rate allowed by the Internal Revenue Service for VOC's. Typically this value has been $0.31-$0.32 per mile. The rates shown in Table 2 are in 1970 dollars. For further explanation of the these values, please refer to the cited reference.

Table 2: Added time and vehicle running cost/1000 stops and idling costs (1970 $)

	Added Time (Hr/1000Stops) (Excludes Idling Time)			Added Cost ($/1000 Stops) (Excludes Idling Time)		
Initial Speed (mi/h)	Pass Cars	Single-Unit Trucks	Combination Truck	Pass Cars	Single-Unit Trucks	Combination Truck
5	1.02	0.73	1.1	0.71	2.43	8.83
10	1.51	1.47	2.27	2.32	5.44	20.35
15	2	2.2	3.48	3.98	8.9	34.13
20	2.49	2.93	4.76	5.71	12.71	49.91
25	2.98	3.67	6.1	7.53	16.8	67.37
30	3.46	4.4	7.56	9.48	21.07	86.19
35	3.94	5.13	9.19	11.57	25.44	106.05
40	4.42	5.87	11.09	13.84	29.93	126.63
45	4.9	6.6	13.39	16.3	34.16	147.62
50	5.37	7.33	16.37	18.99	38.33	168.7
55	5.84	8.07	20.72	21.92	42.25	189.54
60	6.31	8.8	27.94	25.13	47	209.82
65	6.78	9.53	39.06	28.63	51.43	236.41
70	7.25	10.27	50.49	32.46	54.9	261.41
75	7.71	11	65.28	36.64	59.05	287.11
80	8.17	11.74	84.41	41.19	63.21	313.85
Idling Cost ($/Veh-Hr.)				0.1819	0.2017	0.2166

Source: R. Winfrey, Economic Analysis for Highways, and Table 5, NCHRP Report 133--Added Cost ($/1,000 Stops) includes fuel, tires, engine oil, maintenance, and depreciation.--Idling Cost ($/Veh-Hr) includes fuel, engine oil, maintenance, and depreciation.

b. User delay costs

Of all the components of road user costs, the cost rate assigned to user delay (i.e., the value of time) is by far the most controversial. Currently, the user delay cost values being used in the DP-115 program are comprised of earlier research performed in both NCHRP 133 and MicroBENCOST (see Table 3). For information purposes, MicroBENCOST is a comprehensive program utilizing best practical procedures for highway economic analysis.[11] It was developed to replace the 1977 AASHTO "Red Book"-"A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements."[12,13] The values listed in Table 3 are in August 1996 dollars.

Table 3: User delay costs–value of time--(DP-115 program, August 1996 dollars)

Vehicle Type	NCHRP 133 ($/Veh-Hr)	MicroBENCOST ($/Veh-Hr)	Average Value ($/Veh-Hr)
Automobiles	11.78	11.37	11.58
Single Unit Trucks	19.64	17.44	18.54
Combination Unit Trucks	19.64	24.98	22.31

Source: FHWA Report FHWA-SA-98-079, Table 2.7

c. Accident/crash costs

The last cost rate that may be included in total user delay cost is accident/crash costs. Although crash cost are not calculated in the DP-115 and/or KyUCP program, typical fatality ranges between $1,091,000 to $1,182,000 have been established as default values in the MicroBENCOST program.[4] These values are somewhat lower than the $2,700,000 cost per fatality averted, which was recommended by the U.S. Department of Transportation in its March 14, 1995 memorandum from the Assistant Secretary for Transportation Policy to DOT Modal Administrators.[4]

2. Current cost components and their rates used by other agencies

a. VOC rates

It was difficult to make a direct comparison of VOC between different agencies. As shown above, in Table 2, Winfrey defines the additional VOC rates for stopping/speed changes and idling per 1000 stops. This research assumes that the vehicle operator is going to make the trip regardless of the presence of an work zone. Therefore, this approach does not address total vehicle operating costs, it only calculates the added costs incurred by making speed changes/stops. However, the AASHTO Red Book uses total VOC to define VOC associated when making speed changes/stops.[12,13] The typical units used in the AASHTO Red Book are in dollars-per-1000 vehicle-miles.

The researchers feel that the difference between calculating VOC using either added costs or total vehicle operating costs is insignificant in estimating the VOC portion of road user costs. This assumption may be justified by previous research that states "when vehicle demand on the facility exceeds work zone capacity, the facility operates under forced-flow conditions and road user costs can be immense. Queuing costs can account for more than 95 percent of work zone road user costs with the lion's share of the cost being the delay time of crawling through long, slow-moving queues."[4]

b. User delay costs

As mentioned earlier, the cost rate assigned to user delay (i.e., the value of time) is by far the most controversial. Some agencies adopt their own rates based on regional economic data. For instance, North Carolina calculates the value of time based on the average annual hourly wage rate in the county where the analysis is being done.[11] Other agencies have used nationally published data. For a listing of user delay values based on vehicle type, that have been used by other agencies, see Tables 4 through 6. All values displayed below are in 1998 dollars for comparative reasons. Cost rates that have been published in the cited sources in previous/later year dollars will be adjusted by the annual "*All Items*" component of the CPI data for 1998 (value = 163.0).

Table 4: User delay costs: Cars

Reference Source (see references)	Agency	Delay Cost Rate Value ($/Veh-Hr)	Reference Year	Delay Cost Rate Value Adjusted 1998 ($/Veh-Hr)
11	North Carolina	8.70	1998	8.70
11	New York	9.00	1998	9.00
11	Florida	11.12	1998	11.12
11	Georgia	11.65	1998	11.65
11	Texas	11.97	1998	11.97
11	Virginia	11.97	1998	11.97
11	California	12.10	1998	12.10
11	Pennsylvania	12.21	1998	12.21
11	Washington	12.51	1998	12.51
11	Ohio	12.60	1998	12.60
4	NCHRP 133	11.78	1996	12.21
4	MicroBENCOST	11.37	1996	11.78
4	DP 115 Tech. Report	11.58	1996	12.00
4	U.S. DOT - OST	10.80	1996	11.19

Table 4 Cont.: User delay costs: Cars

Reference Source (see references)	Agency	Delay Cost Rate Value ($/Veh-Hr)	Reference Year	Delay Cost Rate Value Adjusted 1998 ($/Veh-Hr)
4	HERS	14.30	1996	14.82
12	AASHTO “Red Book”	9.10	1998	9.10
14	Chui and McFarland	10.81	1998	10.81
	Mean			11.51

Table 5: User delay costs: Combination trucks

Reference Source (see references)	Agency	Delay Cost Rate Value ($/Veh-Hr)	Reference Year	Delay Cost Rate Value Adjusted 1998 ($/Veh-Hr)
11	New York	21.14	1998	21.14
11	Florida	22.36	1998	22.36
11	Texas	21.87	1998	21.87
11	Virginia	21.87	1998	21.87
11	California	30.00	1998	30.00
11	Pennsylvania	24.18	1998	24.18
11	Washington	50.00	1998	50.00
11	Ohio	26.40	1998	26.40
4	NCHRP 133	19.64	1996	20.35
4	MicroBENCOST	24.98	1996	25.86
4	DP 115 Tech. Report	22.31	1996	23.11
4	U.S. DOT - OST	16.50	1996	17.10
4	HERS	31.30	1996	32.43
12	AASHTO “Red Book”	16.60	1998	16.60
14	Chui and McFarland	20.35	1998	20.35
	Mean			24.90

Table 6: User delay costs: Single unit trucks

Reference Source (see references)	Agency	Delay Cost Rate Value ($/Veh-Hr)	Reference Year	Delay Cost Rate Value Adjusted 1998 ($/Veh-Hr)
4	NCHRP 133	19.64	1996	20.35
4	MicroBENCOST	17.44	1996	18.07
4	DP 115 Tech. Report	18.54	1996	19.21
4	U.S. DOT - OST	16.50	1996	17.09
4	HERS	25.99	1996	26.93
	Mean			20.33

c. Accident/crash costs

As outlined in the FHWA Technical Report titled "Life Cycle Cost Analysis in Pavement Design" older accident/crash costs are up-dated by using an escalation factor. This escalation factor is once again based off of the *All Items* component of the Consumer Price Index. The values published below from the Kentucky Transportation report titled "Cost of Kentucky Traffic Collisions 2000" are reported in two different contexts (Table 7). One is in terms of the calculable (economic costs) of motor vehicle collisions on public roads. Which include wage loss, medical expense, administration costs, property damage, and employer costs. The other is called comprehensive costs, which include not only the economic cost components but also a measure of the value of lost quality of life associated with death and injuries. Both the estimated economic and comprehensive costs published in Kentucky's report were provided by the National Highway Safety Council.[16]

Table 7: Accident/crash costs

Reference Source (see references)	Agency	Accident/Crash Costs ($/fatality)	Reference Year	Accident/Crash Costs Adjusted 2000 ($/fatality)
4	MicroBENCOST	1,182,000	1996	1,283,443
4	U.S. DOT	2,700,000	1995	3,025,984
15	FHWA	2,722,548	1991	3,414,179
16	KyDOT (econ)	1,000,000	2000	1,000,000
16	KyDOT (comp)	3,214,290	2000	3,214,290

3. Comparison of user costs rates used in DP-115 and those used by other agencies

a. User delay costs

Figures 15 through 17 are a comparison of the user delay cost rates used in the DP-115 and those that have been used by other agencies by vehicle type.

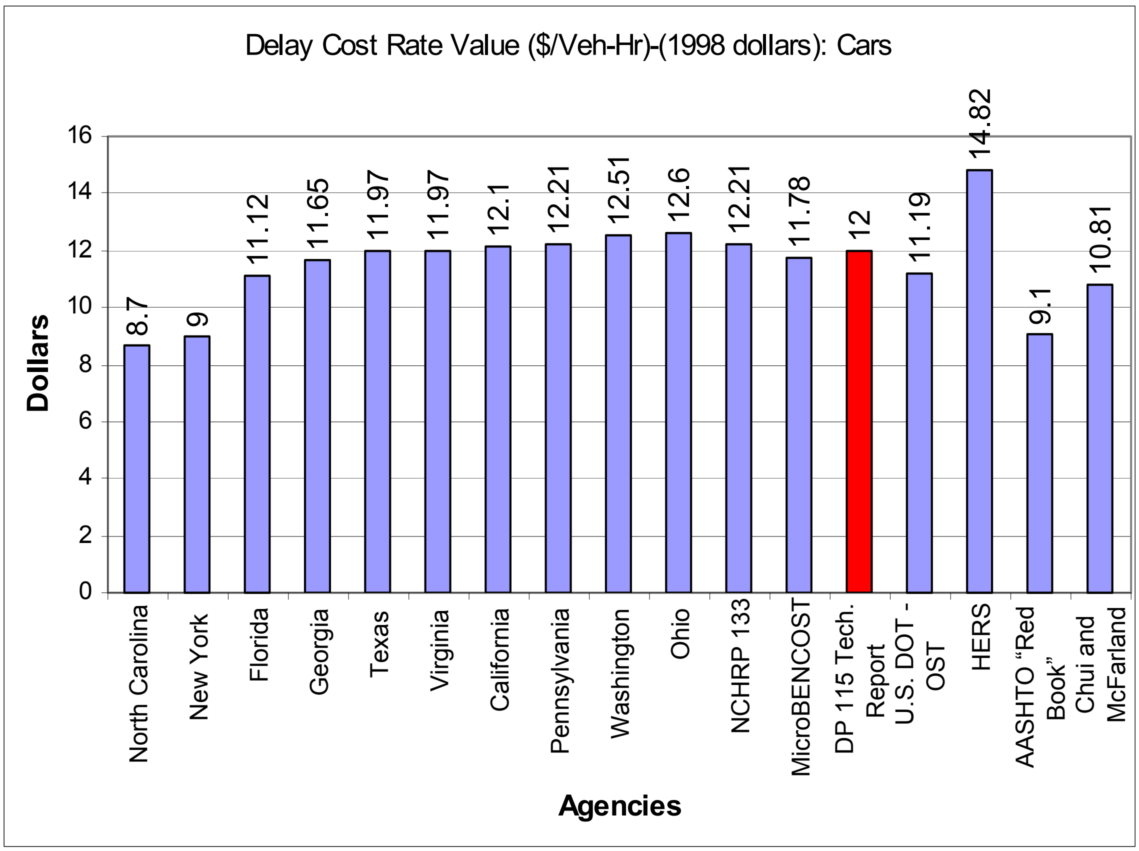

Figure 15: Comparison of user delay costs ($/Veh-Hr)-(1998 dollars): Cars

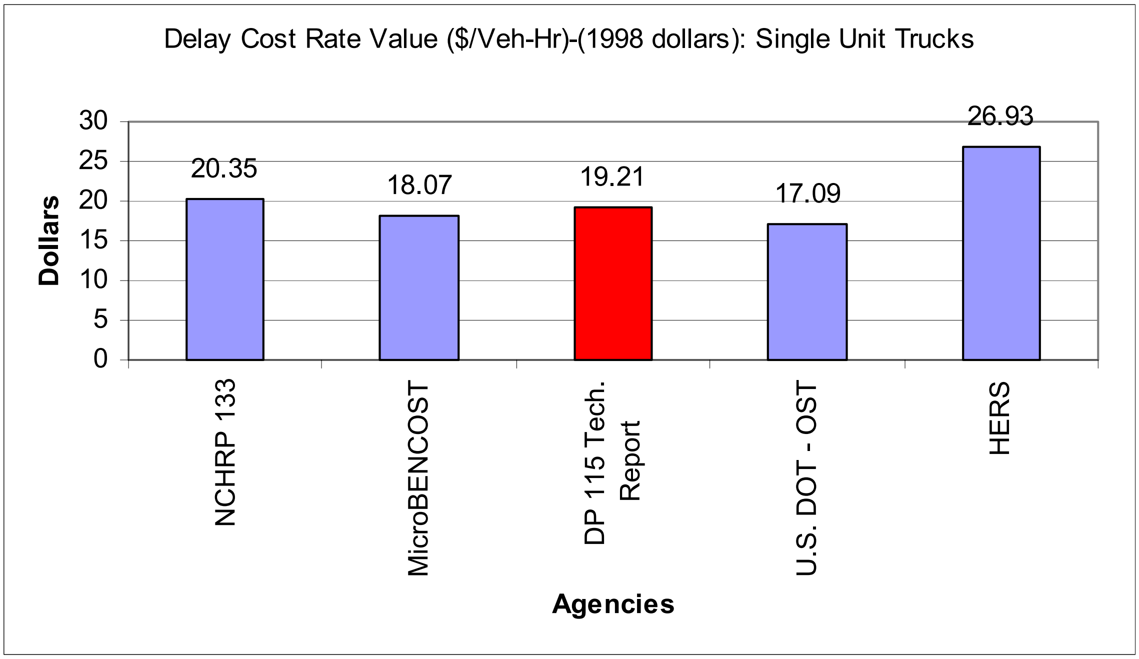

Figure 17: Comparison of user delay costs ($/Veh-Hr)-(1998 dollars): Single Unit Trucks

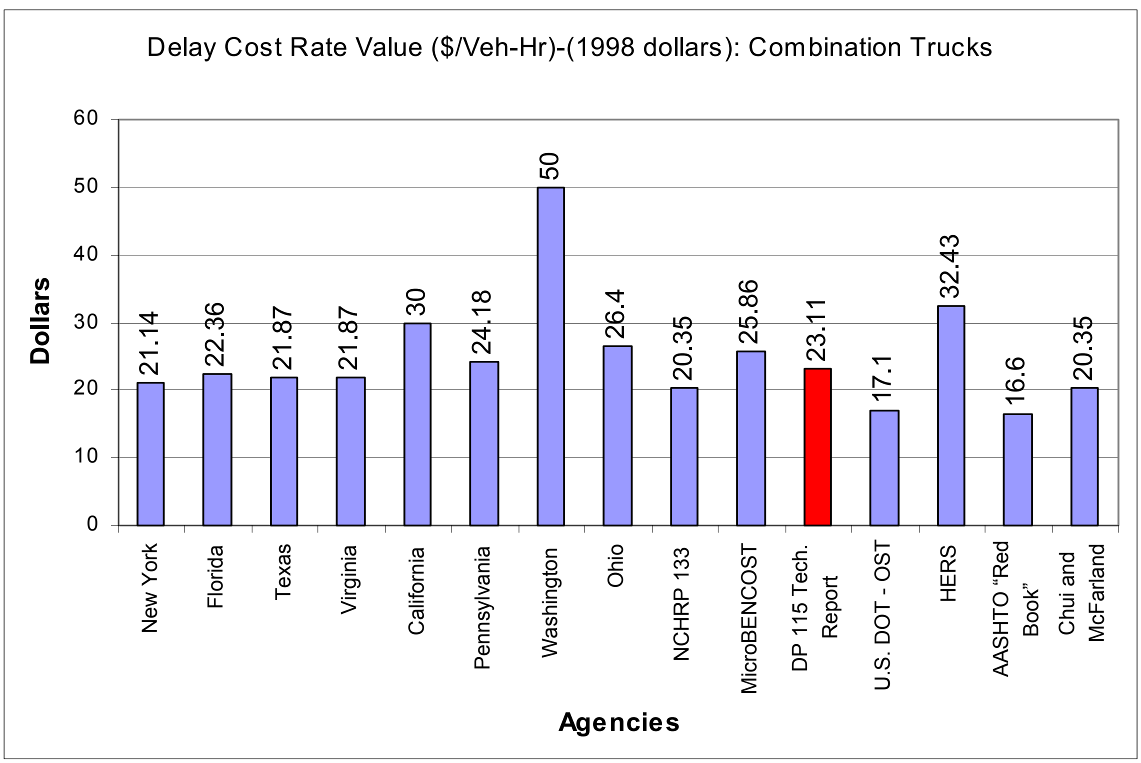

Figure 16: Comparison of user delay costs ($/Veh-Hr)-(1998 dollars): Combination Trucks

b. Accident/crash costs

The author's of the DP-115 technical report do not specify an accident/crash cost to use. Reference is only made to the two sources of information that may be used: MicroBENCOST, and U.S. DOT.

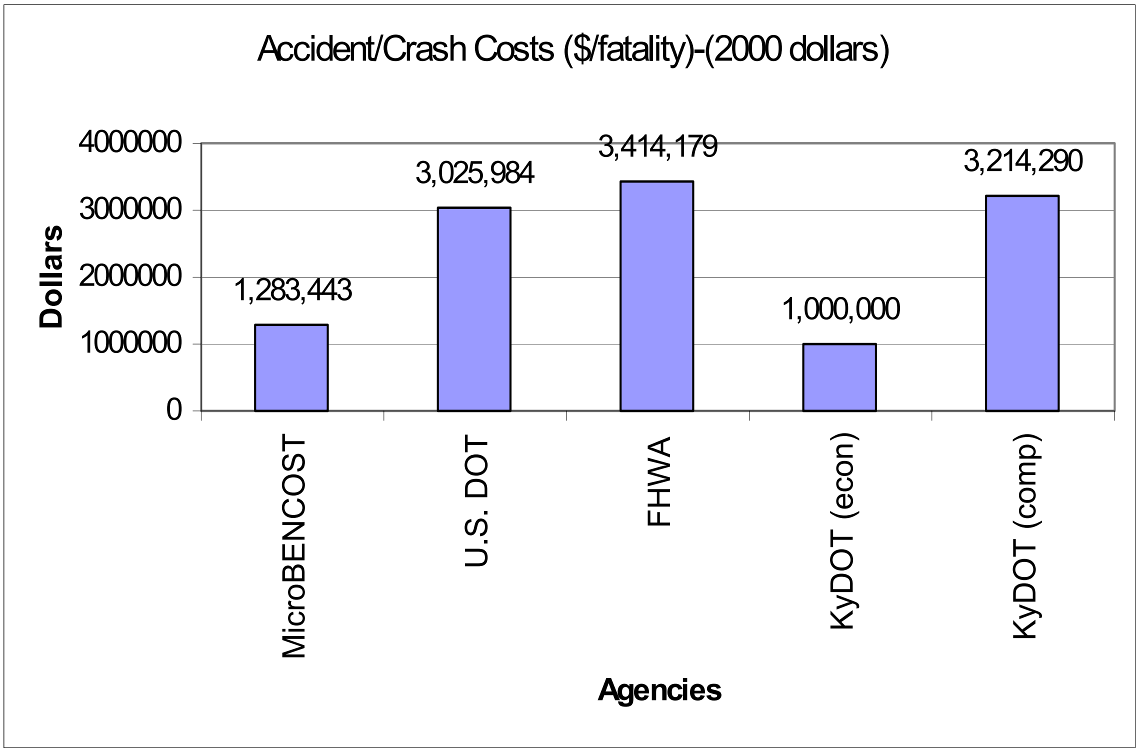

Figure 18: Comparison of accident/crash costs ($/fatality)-(2000 dollars)

VII. Conclusions

Based on the review of three relatively new computer programs that can be used to help quantify delayed traffic incurred by the presence of a work zone, it appears, the program outlined in the DP-115 technical report is more user friendly, and may also be a better tool for defining both the quantity of delayed traffic and queue lengths that are sometimes associated with work zones on interstate highways.

The two equations concerning both short-term and long-term work zone capacities were thoroughly reviewed as well in this study. It appears the short-term work zone capacity equation, which has been used in the 2000 Highway Capacity Manual, may be used with some degree of reliability to estimate short-term work zone capacity. Because the literature search in this study found no information in regards to calculating long-term work zone capacity, a new long-term work zone capacity equation was derived. This equation was based on field data collected in both Indiana and Kentucky.

Although, this equation has not been reviewed by other agencies, it appears it can be used to calculate estimates of long-term work zone capacities.

In regards to road user cost, it is concluded that both the vehicle operating costs, and the user delay costs that are currently being used in the DP-115 program are in line with cost rates currently being used by other agencies. The order of magnitude of the user delay costs being used in the DP-115 program from the mean value of other agencies is \$0.49, \$1.12, and \$1.79 for cars, single unit trucks, and combination trucks, respectively.

VIII. Recommendations

Although DP-115 program has proven itself as a reliable estimation tool for determining total user delay costs associated with highway work zones. It does have it's limitations. The DP-115 program works best for work zones in rural areas, it does not have a feature to calculate road user cost associated with having a work zone that includes a detour. Furthermore the DP-115 program may lack other necessary features needed to perform an appropriate road user cost analysis in an urban area. It is suggested that further research may need to be reviewed and/or developed in this area.

IX. Implementation

After reviewing the three relatively new road user cost programs designed to help pavement designers better define RUC, the researchers modified the DP-115 program to better suit the needs of the Kentucky Transportation Cabinet. The modified program has been titled "Kentucky User Cost Program" or "KyUCP". One may view the program modifications in the "Up-dates to existing program" section of this report.

Currently, the Kentucky Transportation Cabinet has been using the KyUCP to assist in defining road user costs on new rehabilitation projects with a great deal of success. An identical copy of the KyUCP being used by the Kentucky Transportation Cabinet has been included with this report. This media copy has been programmed in a Microsoft Excel 2000 format, and can be found attached to the back cover of this report.

References

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15. FHWA Tech Summary. "The Costs of Highway Crashes", Publication No. FHWA-RD-91-055. June 1991.

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Appendix A

County	Franklin
Route	I-64
Direction	west
Date	5/18/1999
Barrier Type	drums
Work Activity	Asph. Resurf.
Intensity Factor	0
Number of lanes	2
Open lanes during construction	1
Construction Zone lane width (ft.)	11
Bi-directional split	0.5
Work Zone length (miles)	2.3
CPI "all items" (nov. 2001)	177.4
CPI "transportation" (nov. 2001)	150.2
Construction Zone Speed	55
Percent passenger cars	69
milepoint	57
Percent Single Unit Trucks	8
Percent Multiple Unit Trucks	23
ADT two direction	32958
Free Flow Speed	65
Terrain	rolling
Calculated Normal Capacity (vph)	1444
Calculated Work Zone Capacity (vph)	1092

Hour	Work zone in place	Volume one direction (vph)	Field measured delay (miles)	Project Delay using DP 115 (miles)	Project Delay using H.C.M. 1994 (miles)	Hourly User Costs ($)
0	yes	286	0.00	na	na	84
1	yes	221	0.00	na	na	65
2	yes	182	0.00	na	na	54
3	yes	245	0.00	na	na	72
4	yes	333	0.00	na	na	98
5	yes	502	0.00	na	na	148
6	yes	490	0.00	na	na	144
7	yes	899	0.00	na	na	265
8	yes	917	0.00	na	na	270
9	yes	782	0.00	na	na	231
10	yes	766	0.00	na	na	226
11	yes	933	0.00	na	na	275
12	yes	870	0.00	na	na	257
13	yes	865	0.00	na	na	255
14	yes	1036	0.00	na	na	305
15	yes	1152	0.10	0.21	0.11	1377
16	yes	1255	0.60	1.01	0.54	3465
17	yes	1285	1.95	2.30	1.21	6722
18	yes	810	1.00	1.88	1.04	5368
19	yes	668	0.00	0.45	0.25	664
20	yes	623	0.00	na	na	184
21	yes	544	0.00	na	na	160
22	yes	446	0.00	na	na	132
23	yes	369	0.00	na	na	109
Total		16479	3.65	5.85	3.16	20,931

County	Franklin
Route	I-64
Direction	west
Date	5/26/1999
Barrier Type	drums
Work Activity	Asph. Resurf.
Intensity Factor	0
Number of lanes	2
Open lanes during construction	1
Construction Zone lane width (ft.)	11
Bi-directional split	0.5
Work Zone length (miles)	2.3
CPI "all items" (nov. 2001)	177.4
CPI "transportation" (nov. 2001)	150.2
Construction Zone Speed	55
Percent passenger cars	70
milepoint	57
Percent Single Unit Trucks	8
Percent Multiple Unit Trucks	22
ADT two direction	31970
Free Flow Speed	65
Terrain	rolling
Calculated Normal Capacity (vph)	1459
Calculated Work Zone Capacity (vph)	1103

Hour	Work zone in place	Volume one direction (vph)	Field measured delay (miles)	Project Delay using DP 115 (miles)	Project Delay using H.C.M. 1994 (miles)	Hourly User Costs ($)
0	yes	290	0.00	na	na	83
1	yes	225	0.00	na	na	65
2	yes	188	0.00	na	na	54
3	yes	266	0.00	na	na	77
4	yes	333	0.00	na	na	96
5	yes	502	0.00	na	na	144
6	yes	636	0.00	na	na	183
7	yes	721	0.00	na	na	208
8	yes	879	0.00	na	na	253
9	yes	975	0.00	na	na	281
10	yes	749	0.00	na	na	216
11	yes	917	0.00	na	na	264
12	yes	804	0.00	na	na	231
13	yes	973	0.00	na	na	280
14	yes	911	0.00	na	na	262
15	yes	934	0.00	na	na	269
16	yes	1354	0.50	0.90	0.48	3219
17	yes	813	0.90	0.85	0.48	2422
18	yes	845	0.00	na	na	243
19	yes	707	0.00	na	na	203
20	yes	621	0.00	na	na	179
21	yes	534	0.00	na	na	154
22	yes	450	0.00	na	na	130
23	yes	358	0.00	na	na	103
Total		15985	1.40	1.75	0.95	9,618

County	Kenton
Route	I-75
Direction	north
Date	9/5/2001
Barrier Type	drums
Work Activity	spot slab replacement
Intensity Factor	-80
Number of lanes	3
Open lanes during construction	2
Construction Zone lane width (ft.)	11
Bi-directional split	0.5
Work Zone length (miles)	1
CPI "all items" (nov. 2001)	177.4
CPI "transportation" (nov. 2001)	150.2
Construction Zone Speed	45
Percent passenger cars	82
milepoint	189
Percent Single Unit Trucks	3
Percent Multiple Unit Trucks	15
ADT two direction	81000
Free Flow Speed	55
Terrain	rolling
Calculated Normal Capacity (vph)	1594
Calculated Work Zone Capacity (vph)	1323

Hour	Work zone in place	Volume one direction (vph)	Field measured delay (miles)	Project Delay using DP 115 (miles)	Project Delay using H.C.M. 1994 (miles)	Hourly User Costs ($)
0	yes	729		na	na	108
1	yes	607.5		na	na	90
2	yes	526.5		na	na	78
3	yes	526.5		na	na	78
4	yes	607.5		na	na	90
5	yes	729		na	na	108
6	yes	1012.5		na	na	149
7	yes	1417.5		na	na	209
8	yes	1701		na	na	251
9	yes	2025		na	na	299
10	yes	2187		na	na	323
11	yes	2268		na	na	335
12	yes	2308.5		na	na	341
13	yes	2592		na	na	382
14	yes	2754		0.29	0.14	1999
15	yes	2956.5		1.45	0.66	5613
16	yes	3766.5	4.00	5.85	2.47	19403
17	yes	2835	8.00	8.87	4.13	28338
18	yes	2227.5	7.00	7.78	3.84	24788
19	yes	1903.5	4.00	4.67	2.37	15125
20	yes	1539		1.37	0.72	2609
21	yes	1296		na	na	191
22	yes	1053		na	na	155
23	yes	931.5		na	na	137
Total		40500	23.00	30.28	14.32	101,197

County	Franklin
Route	I-64
Direction	east
Date	6/4/1999
Barrier Type	drums
Work Activity	Asph. Resurf.
Intensity Factor	0
Number of lanes	2
Open lanes during construction	1
Construction Zone lane width (ft.)	11
Bi-directional split	0.5
Work Zone length (miles)	3.3
CPI "all items" (nov. 2001)	177.4
CPI "transportation" (nov. 2001)	150.2
Construction Zone Speed	55
Percent passenger cars	76
milepoint	57
Percent Single Unit Trucks	4
Percent Multiple Unit Trucks	20
ADT two direction	38440
Free Flow Speed	65
Terrain	rolling
Calculated Normal Capacity (vph)	1555
Calculated Work Zone Capacity (vph)	1176

Hour	Work zone in place	Volume one direction (vph)	Field measured delay (miles)	Project Delay using DP 115 (miles)	Project Delay using H.C.M. 1994 (miles)	Hourly User Costs ($)
0	yes	241	0.00	na	na	71
1	yes	197	0.00	na	na	58
2	yes	155	0.00	na	na	45
3	yes	130	0.00	na	na	38
4	yes	188	0.00	na	na	55
5	yes	335	0.00	na	na	98
6	yes	795	0.00	na	na	233
7	yes	811	0.00	na	na	238
8	yes	807	0.10	na	na	237
9	yes	820	0.30	na	na	240
10	yes	834	0.40	na	na	245
11	yes	1037	0.30	na	na	304
12	yes	1004	0.20	na	na	294
13	yes	1112	0.00	na	na	326
14	yes	1109	0.75	na	na	325
15	yes	1127	1.00	na	na	331
16	yes	1282	1.00	0.35	0.20	1789
17	yes	1289	2.00	1.07	0.62	3683
18	yes	1397	2.50	2.20	1.25	6689
19	yes	1322	3.80	3.40	1.94	9780
20	yes	1099	2.00	3.55	2.07	10041
21	yes	959	0.70	2.56	1.52	7379
22	yes	633	0.25	0.90	0.55	1629
23	yes	537	0.00	na	na	157
Total		19220	15.30	14.05	8.15	44,287

County	Hardin
Route	I-65
Direction	north
Date	8/14/2001
Barrier Type	drums
Work Activity	full slab replacement
Intensity Factor	0
Number of lanes	3
Open lanes during construction	1
Construction Zone lane width (ft.)	11
Bi-directional split	0.5
Work Zone length (miles)	4
CPI "all items" (nov. 2001)	177.4
CPI "transportation" (nov. 2001)	150.2
Construction Zone Speed	55
Percent passenger cars	70
milepoint	97
Percent Single Unit Trucks	4
Percent Multiple Unit Trucks	26
ADT two direction	45000
Free Flow Speed	65
Terrain	rolling
Calculated Normal Capacity (vph)	1460
Calculated Work Zone Capacity (vph)	1103

Hour	Work zone in place	Volume one direction (vph)	Field measured delay (miles)	Project Delay using DP 115 (miles)	Project Delay using H.C.M. 1994 (miles)	Hourly User Costs ($)
0	yes	405		4.83	3.13	21671
1	yes	337.5		1.98	1.29	9097
2	yes	292.5		0.24	0.16	328
3	yes	292.5		na	na	115
4	yes	337.5		na	na	133
5	yes	405		na	na	160
6	yes	562.5	0	na	na	222
7	yes	787.5	0	na	na	310
8	yes	945	0	na	na	372
9	yes	1125	0.01	0.04	0.03	1161
10	yes	1215	0.06	0.32	0.20	2425
11	yes	1260	0.16	0.87	0.54	4880
12	yes	1282.5	1.75	1.56	0.96	7932
13	yes	1440	2.19	2.65	1.61	12808
14	yes	1530	2.84	4.26	2.58	19929
15	yes	1642.5	4.06	6.33	3.80	29052
16	yes	2092.5		9.83	5.73	44707
17	yes	1575		12.56	7.57	56340
18	yes	1237.5		13.54	8.34	60391
19	yes	1057.5		13.56	8.45	60395
20	yes	855		12.81	8.08	56943
21	yes	720		11.45	7.29	50899
22	yes	585		9.58	6.15	42622
23	yes	517.5		7.38	4.75	32921
Total		22500		114	71	515,811

County	Franklin
Route	I-64
Direction	west
Date	6/4/1999
Barrier Type	drums
Work Activity	Asph. Resurf.
Intensity Factor	0
Number of lanes	2
Open lanes during construction	1
Construction Zone lane width (ft.)	11
Bi-directional split	0.5
Work Zone length (miles)	3.3
CPI "all items" (nov. 2001)	177.4
CPI "transportation" (nov. 2001)	150.2
Construction Zone Speed	55
Percent passenger cars	76
milepoint	57
Percent Single Unit Trucks	4
Percent Multiple Unit Trucks	20
ADT two direction	38440
Free Flow Speed	65
Terrain	rolling
Calculated Normal Capacity (vph)	1555
Calculated Work Zone Capacity (vph)	1176

Hour	Work zone in place	Volume one direction (vph)	Field measured delay (miles)	Project Delay using DP 115 (miles)	Project Delay using H.C.M. 1994 (miles)	Hourly User Costs ($)
0	yes	241	0.00	na	na	76
1	yes	197	0.00	na	na	62
2	yes	155	0.00	na	na	49
3	yes	130	0.00	na	na	41
4	yes	188	0.00	na	na	59
5	yes	335	0.00	na	na	106
6	yes	795	0.00	na	na	251
7	yes	811	0.00	na	na	256
8	yes	807	0.90	na	na	255
9	yes	820	0.10	na	na	259
10	yes	834	0.10	na	na	264
11	yes	1037	0.10	na	na	328
12	yes	1004	0.90	na	na	317
13	yes	1112	0.10	na	na	351
14	yes	1109	0.90	na	na	351
15	yes	1127	0.90	na	na	356
16	yes	1282	1.70	0.35	0.20	1619
17	yes	1289	1.70	1.07	0.62	3512
18	yes	1397	2.20	2.20	1.25	6502
19	yes	1322	3.80	3.40	1.94	9604
20	yes	1099	2.00	3.55	2.07	9899
21	yes	959	0.70	2.56	1.52	7259
22	yes	633	0.00	0.90	0.55	1598
23	yes	537	0.00	na	na	170
Total		19220	16.10	14.05	8.15	43,544

County	Scott
Route	I-75
Direction	north
Date	8/21/2001
Barrier Type	cones
Work Activity	Asp. Resurf/striping
Intensity Factor	80
Number of lanes	3
Open lanes during construction	1
Construction Zone lane width (ft.)	11
Bi-directional split	0.5
Work Zone length (miles)	3.4
CPI "all items" (nov. 2001)	177.4
CPI "transportation" (nov. 2001)	150.2
Construction Zone Speed	55
Percent passenger cars	85
milepoint	125
Percent Single Unit Trucks	2
Percent Multiple Unit Trucks	13
ADT two direction	39000
Free Flow Speed	65
Terrain	rolling
Calculated Normal Capacity (vph)	1727
Calculated Work Zone Capacity (vph)	1241

Hour	Work zone in place	Volume one direction (vph)	Field measured delay (miles)	Project Delay using DP 115 (miles)	Project Delay using H.C.M. 1994 (miles)	Hourly User Costs ($)
0	yes	351		na	na	94
1	yes	293		na	na	78
2	yes	254		na	na	68
3	yes	254		na	na	68
4	yes	293		na	na	78
5	yes	351	0.1	na	na	94
6	yes	488	0.1	na	na	130
7	yes	683	0.0	na	na	182
8	yes	819	0.0	na	na	218
9	no	975		na	na	0
10	no	1053		na	na	0
11	no	1092		na	na	0
12	no	1112		na	na	0
13	no	1248		na	na	0
14	no	1326		na	na	0
15	no	1424		na	na	0
16	no	1814		na	na	0
17	no	1365		na	na	0
18	no	1073		na	na	0
19	no	917		na	na	0
20	yes	741		na	na	197
21	yes	624		na	na	166
22	yes	507		na	na	135
23	yes	449		na	na	120
Total		19500	0	0	0	1,626

Appendix B

County	Kenton
Route	I-75
Direction	south
Date	9/5/2001
Barrier Type	barrier wall
Work Activity	median barrier wall
Intensity Factor	0
Number of lanes	4
Open lanes during construction	2
Construction Zone lane width (ft.)	12
Bi-directional split	0.5
Work Zone length (miles)	2.5
CPI "all items" (nov. 2001)	177.4
CPI "transportation" (nov. 2001)	150.2
Construction Zone Speed	45
Percent passenger cars	84
milepoint	185
Percent Single Unit Trucks	2
Percent Multiple Unit Trucks	14
ADT two direction	100000
Free Flow Speed	55
Terrain	rolling
Calculated Normal Capacity (vph)	1706
Calculated Work Zone Capacity (vph)	1615

Hour	Work zone in place	Volume one direction (vph)	Field measured delay (miles)	Project Delay using DP 115 (miles)	Project Delay using H.C.M. 1994 (miles)	Hourly User Costs ($)
0	yes	900		na	na	213
1	yes	750		na	na	177
2	yes	650		na	na	154
3	yes	650		na	na	154
4	yes	750		na	na	177
5	yes	900		na	na	213
6	yes	1250		na	na	296
7	yes	1750		na	na	414
8	yes	2100		na	na	497
9	yes	2500		na	na	591
10	yes	2700		na	na	638
11	yes	2800		na	na	662
12	yes	2850		na	na	674
13	yes	3200		na	na	757
14	yes	3400		0.01	0.01	1708
15	yes	3650	0.50	0.48	0.26	3973
16	yes	4650	2.25	3.36	1.70	17741
17	yes	3500	3.75	5.50	2.99	27320
18	yes	2750	3.50	4.36	2.48	21768
19	yes	2350	0.50	1.61	0.94	8385
20	yes	1900		na	na	449
21	yes	1600		na	na	378
22	yes	1300		na	na	307
23	yes	1150		na	na	272
Total		50000	10.50	15.33	8.37	87,918

County	Kenton
Route	I-75
Direction	south
Date	8/30/2001
Barrier Type	barrier wall
Work Activity	median barrier wall
Intensity Factor	0
Number of lanes	4
Open lanes during construction	2
Construction Zone lane width (ft.)	12
Bi-directional split	0.5
Work Zone length (miles)	2.5
CPI "all items" (nov. 2001)	177.4
CPI "transportation" (nov. 2001)	150.2
Construction Zone Speed	45
Percent passenger cars	88
milepoint	185
Percent Single Unit Trucks	2
Percent Multiple Unit Trucks	10
ADT two direction	100000
Free Flow Speed	55
Terrain	rolling
Calculated Normal Capacity (vph)	1716
Calculated Work Zone Capacity (vph)	1696

Hour	Work zone in place	Volume one direction (vph)	Field measured delay (miles)	Project Delay using DP 115 (miles)	Project Delay using H.C.M. 1994 (miles)	Hourly User Costs ($)
0	yes	900		na	na	197
1	yes	750		na	na	164
2	yes	650		na	na	142
3	yes	650		na	na	142
4	yes	750		na	na	164
5	yes	900		na	na	197
6	yes	1250		na	na	273
7	yes	1750		na	na	382
8	yes	2100		na	na	459
9	yes	2500		na	na	546
10	yes	2700		na	na	590
11	yes	2800		na	na	612
12	yes	2850		na	na	623
13	yes	3200		na	na	699
14	yes	3400		0.01	0.01	1535
15	yes	3650	0.98	0.48	0.26	3721
16	yes	4650	3.50	3.36	1.70	17023
17	yes	3500	4.25	5.50	2.99	26342
18	yes	2750	3.25	4.36	2.48	20990
19	yes	2350	0.25	1.61	0.94	8043
20	yes	1900		na	na	415
21	yes	1600		na	na	350
22	yes	1300		na	na	284
23	yes	1150		na	na	251
Total		50000	12.23	15.33	8.37	84,142

County	Jefferson
Route	I-264
Direction	west
Date	6/11/1999
Barrier Type	barrier wall
Work Activity	widening
Intensity Factor	0
Number of lanes	2
Open lanes during construction	1
Construction Zone lane width (ft.)	12
Bi-directional split	0.5
Work Zone length (miles)	2.8
CPI "all items" (nov. 2001)	177.4
CPI "transportation" (nov. 2001)	150.2
Construction Zone Speed	55
Percent passenger cars	84
milepoint	
Percent Single Unit Trucks	5
Percent Multiple Unit Trucks	11
ADT two direction	40488
Free Flow Speed	65
Terrain	rolling
Calculated Normal Capacity (vph)	1706
Calculated Work Zone Capacity (vph)	1615

Hour	Work zone in place	Volume one direction (vph)	Field measured delay (miles)	Project Delay using DP 115 (miles)	Project Delay using H.C.M. 1994 (miles)	Hourly User Costs ($)
0	yes	365	na	na	na	84
1	yes	304	na	na	na	70
2	yes	263	na	na	na	60
3	yes	263	na	na	na	60
4	yes	304	na	na	na	70
5	yes	365	na	na	na	84
6	yes	506	na	na	na	116
7	yes	709	na	na	na	162
8	yes	851	na	na	na	195
9	yes	1013	na	na	na	232
10	yes	1094	na	na	na	251
11	yes	1134	na	na	na	260
12	yes	1154	na	na	na	265
13	yes	1296	na	na	na	297
14	yes	1377	na	na	na	316
15	yes	1478	na	na	na	339
16	yes	1883	0.50	0.91	0.51	3171
17	yes	1418	0.65	1.10	0.64	3433
18	yes	1114	0.25	0.22	0.13	387
19	yes	952	na	na	na	218
20	yes	770	na	na	na	176
21	yes	648	na	na	na	149
22	yes	527	na	na	na	121
23	yes	466	na	na	na	107
Total		20250	1.40	2.23	1.28	10,620

County	Madison
Route	I-75
Direction	south
Date	11/21/2001
Barrier Type	barrier wall
Work Activity	road widening
Intensity Factor	0
Number of lanes	3
Open lanes during construction	2
Construction Zone lane width (ft.)	12
Bi-directional split	0.5
Work Zone length (miles)	5
CPI "all items" (nov. 2001)	177.4
CPI "transportation" (nov. 2001)	150.2
Construction Zone Speed	55
Percent passenger cars	90
milepoint	82
Percent Single Unit Trucks	2
Percent Multiple Unit Trucks	8
ADT two direction	46800
Free Flow Speed	65
Terrain	rolling
Calculated Normal Capacity (vph)	1839
Calculated Work Zone Capacity (vph)	1738

Hour	Work zone in place	Volume one direction (vph)	Field measured delay (miles)	Project Delay using DP 115 (miles)	Project Delay using H.C.M. 1994 (miles)	Hourly User Costs ($)
0	yes	421		na	na	124
1	yes	351		na	na	103
2	yes	304		na	na	90
3	yes	304		na	na	90
4	yes	351		na	na	103
5	yes	421		na	na	124
6	yes	585		na	na	172
7	yes	819		na	na	241
8	yes	983		na	na	290
9	yes	1170		na	na	345
10	yes	1264		na	na	373
11	yes	1310		na	na	386
12	yes	1334		na	na	393
13	yes	1498		na	na	442
14	yes	1591	0.00	na	na	469
15	yes	1708	0.00	na	na	504
16	yes	2176	0.00	na	na	642
17	yes	1638	0.00	na	na	483
18	yes	1287		na	na	379
19	yes	1100		na	na	324
20	yes	889		na	na	262
21	yes	749		na	na	221
22	yes	608		na	na	179
23	yes	538		na	na	159
Total		23400	0.00	0.00	0.00	6,899

County	Woodford
Route	I-64
Direction	west
Date	10/24/2001
Barrier Type	barrier wall
Work Activity	Bridge Hydro Demo.
Intensity Factor	0
Number of lanes	2
Open lanes during construction	1
Construction Zone lane width (ft.)	12
Bi-directional split	0.5
Work Zone length (miles)	0.25
CPI "all items" (nov. 2001)	177.4
CPI "transportation" (nov. 2001)	150.2
Construction Zone Speed	55
Percent passenger cars	82
milepoint	77
Percent Single Unit Trucks	3
Percent Multiple Unit Trucks	15
ADT two direction	27500
Free Flow Speed	65
Terrain	rolling
Calculated Normal Capacity (vph)	1665
Calculated Work Zone Capacity (vph)	1577

Hour	Work zone in place	Volume one direction (vph)	Field measured delay (miles)	Project Delay using DP 115 (miles)	Project Delay using H.C.M. 1994 (miles)	Hourly User Costs ($)
0	yes	248		na	na	36
1	yes	206		na	na	30
2	yes	179		na	na	26
3	yes	179		na	na	26
4	yes	206		na	na	30
5	yes	248		na	na	36
6	yes	344		na	na	50
7	yes	481		na	na	70
8	yes	578		na	na	84
9	yes	688		na	na	100
10	yes	743		na	na	108
11	yes	770		na	na	112
12	yes	784		na	na	114
13	yes	880		na	na	128
14	yes	935		na	na	136
15	yes	1004	0.00	na	na	146
16	yes	1279	0.00	na	na	185
17	yes	963		na	na	140
18	yes	756		na	na	110
19	yes	646		na	na	94
20	yes	523		na	na	76
21	yes	440		na	na	64
22	yes	358		na	na	52
23	yes	316		na	na	46
Total		13750	0.00	0.00	0.00	1,994